Journal of South Pacific Agriculture, Volume 24, 2021
http://www.journalofsouthpacificagriculture.com/index.php/JOSPA

Effects of a Pasture-based rearing system on Egg production of Hy-line Brown laying-hens in Papua New Guinea

Jeremiah Ahizo[1*], Stanley Amben[1], Martin W. Lobâo[2], Arthur D. Roberts[3], and Janet Pandi[3]

ABSTRACT

Substantial efforts have been made using non-conventional feed sources as least-cost options for feeding poultry. Complementary work on alternate rearing systems for additional income and diversifying production options is equally important. Egg production of 96 Hy-line Brown laying-hens reared under a pasture-based vs. conventional rearing system was investigated in this study. The former involved providing laying-hens with outdoor-access to propagated kikuyu-white clover pastures and restricting feed offer by 50 %. The latter were kept indoors and fed a standard layer ration *ad libitum*. A complete randomized design was used with four replicates per production system; each with 12 birds randomly assigned to eight experimental pens. Feed conversion ratio (FCR), hen-day egg production (HDEP), egg weights and production costs were measured over eight weeks. Pasture-hens consumed less feed (99.7 g, b^{-1} vs. 123.9 g, b^{-1}; $P = 0.002$) and achieved better FCR (1.98 vs. 2.22; $P=0.009$) than conventional-hens. Pasture-hens also laid less eggs (10, d^{-1} vs. 11, d^{-1}; $P =0.015$), attained lower HDEP (80.8 % vs. 90.2 %; $P=0.015$) and their eggs were less heavy (52.9 g, egg^{-1} vs. 55.9 g, egg^{-1}; $P = 0.005$). However, these eggs were cheaper to produce (PGK0.40, egg^{-1} vs. PGK0.45, egg^{-1}; $P=0.035$) with significantly better benefit-cost ratios (1.74 vs. 1.57; $P=0.032$). Despite its relatively low HDEP, the pasture-based rearing system provides an economically viable alternative that can be incorporated into existing farming systems. Additional studies on raising various laying genotypes under pasture-based systems, over year-long cycles are needed to ascertain its long-term potential and economic viability.

Keywords: Pasture, laying-hens, feed conversion, hen-day egg production, benefit-cost ratio

INTRODUCTION

Smallholder livestock farming is vital for providing animal-based food products and as an income source for many resource-poor farmers in developing countries (Makkar, 2006). In Papua New Guinea (PNG), poultry production has become an important industry, providing thousands of jobs, food, and income for its growing population. Characterized by low input requirements and fast turnover rates, poultry production is regarded as a commercially viable enterprise currently supporting the livelihoods of around 50, 000 households (Glatz, 2007; Jack, 2014). Over many years, this industry's success has relied on intensive (conventional) production systems to meet the growing demand for meat and egg products. This production system is predominantly practised by smallholder farmers in PNG, where birds are raised in confinement with no access to the outdoor environment. The main reason for the extensive use of this system is to maximize meat or egg yield and minimize production costs (Inci et al., 2016). Be that as it may, production is often constrained by high input costs particularly due to heavy reliance on commercial feed.

Moreover, intensive production systems raise some issues regarding food safety for human health and animal well-being (Inci et al., 2016). According to Dozier et al. (2005) birds kept intensively experience overcrowding, undergo high stress levels, and are more prone to diseases. Further still, concerns are being raised about the conditions in which chickens are raised and its impact on meat and egg quality for human consumption (Husak et al., 2008; Wang et al., 2009). Consequently, there has been an increasing demand for products generated from pasture-poultry, free-range and organic farming systems. This was related to the greater quality and security of meat and eggs derived from such production systems along with high standards of animal welfare (Fanatico et al., 2005).

In PNG, a modern and vertically integrated production system is operated by commercial entities to supply frozen carcasses and table-eggs to the formal market. Smallholder farmers operate independently from these entities, raising and selling an estimated 6 million birds through local informal markets each year (Glatz, 2007). Most of the eggs available through the formal market is usually supplied by commercial entities. Even so, interest is growing with a few semi-commercial and small-scale enterprises currently involved in egg production targeting both the informal and formal markets within their locality. However, the profitability of small-scale egg producing enterprises is primarily constrained by high operational feed costs.

[1]National Agriculture Research Institute (NARI), Highlands Regional Centre - Tambul, P.O. Box 120, Mt. Hagen, Western Highlands, PNG
[2]NARI, Islands Regional Centre - Keravat, P.O. Box 204, Kokopo, East New Britain, PNG
[3]NARI, Momase Regional Centre - Labu, P.O. Box 1639, Lae 411, Morobe, PNG

*Corresponding e-mail: ahizojeremiah37@gmail.com

As most dietary sources in poultry feed are imported (Glatz, 2007) commercial feed prices continue to rise (Error! Reference source not found.) and this trend is likely to continue in future because PNG is not self-sufficient in cereal crop production. Worse still, the phenomenon of food-feed competition would result in competing availability of quality feedstuff rendering poultry feed to remain costly (Hussain et al., 2012).

Table 1. Changes in the average retail prices of broiler starter, finisher, and layer rations from a reputable supplier in Mt. Hagen from 2013 to 2018

	Price (PGK[a])					
Feed type	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Starter	85.0	92.0	86.0	86.5	85.5	87.0
Finisher	83.0	88.5	84.0	84.5	82.5	85.0
Egg layer	100.0	130.0	110.0	115.0	118.0	130.0

[a] PGK = PNG Kina.
Source: Archives of NARI livestock projects, from poultry feed purchase records.

Since 2000, research efforts have continuously focused on the need to efficiently utilize locally available feed resources for raising poultry in PNG (Quartermain, 2001; Healy, 2001 in Glatz, 2007). Several studies on the use of non-conventional feed sources have been made with some success, particularly in using agro-industrial by-products for broiler feeding such as copra meal (Nano, 2015), rice bran (Solomon et al., 2017) and root and tuber crops like sweet potato (Ayalew, 2017; Pandi 2017) and cassava (Nano, 2015; Solomon et al., 2016; Ahizo et al., 2017). Use of local feedstuff in feeding several genotypes of laying-hens include sweet potato (Besari et al., 2017ab) and cassava (Ahizo et al., 2017; Besari et al., 2017ab). However, these assessments were focused more on poultry nutrition and less on alternative rearing systems.

An alternative described by Sossidou et al. (2011) is pasture-poultry where meat and egg-laying genotypes are provided access to either cultivated or natural pasture. Such systems require minimal resource input with reduced stocking densities and pasture utilization (Bogosavljevic-Boskovic et al., 2012). Poultry are allowed daily access to grass, seeds, and insects (Fanatico et al., 2007) when weather conditions are favourable (Glatz, 2007). Bancos (2010 in Bogosavljevic-Boskovic et al., 2012) ascribe such systems as better conditions for birds with improved well-being and poses lower risks to human health. Rearing birds this way is also accepted as being natural and is perceived to provide meat and eggs with distinct sensory qualities (Glatz, 2007; Chen et al., 2013). Even the more affluent and health-conscious consumers are willing to pay more for such products, creating a specialty market (Bartlett et al., 2015).

There is limited research on the feasibility of producing pasture-poultry meat and egg products in PNG. Information on the impact of alternative rearing systems on poultry growth and productivity including meat and egg characteristics is scarce. This study investigated the possibility of raising laying-hens on propagated kikuyu-white clover pastures. It tested the hypothesis that the pasture-based production system will not affect egg production.

MATERIALS AND METHODS

Study area

The study was conducted on-station using existing research facilities at NARI's Highlands Regional Centre, Tambul (5.942 °S, 144.0113 °E, at 2,200 m above sea level) from November to December 2017. According to Hanson et al. (2001), the yearly rainfall and relative humidity (RH) levels vary from 2, 300 to 4, 000 mm and 65 to 75 % respectively, while temperatures range between 18 and 20 °C. The recorded rainfall during the study period was 327 mm with observed indoor; outdoor temperature and RH levels of 17-26 °C; 15-25 °C and 35-75 %; 30-72 % accordingly with a 12-hour (12L:12D) photoperiod.

Experimental birds, housing, and experimental design

A total of 96 Hy-line Brown day-old chicks supplied by the Zenag Hatchery (Lae, Morobe) were used in this study. The study was conducted in a naturally ventilated shed with a concrete floor, outer v-crimp walls, and corrugated iron roofing. All experimental pens were partitioned with mesh wire and had an equal floor spacing of 5 m^2 each. Wood shavings were spread, at a depth of 10 cm, on the floors of all pens as bedding material. The layout was a completely randomized design involving two rearing systems (pasture-based vs. conventional), each with four replicates and 12 hens, randomly distributed into eight experimental units.

Pasture establishment, feeding, and management

Kikuyu (*Pennisetum clandestinum*) and white clover (*Trifolium repens* L.) pastures were propagated through rhizomes and stolons planted in opposing rows using a spacing of 30 cm between and 10 cm within rows and fertilized with poultry manure. These pasture species are widely available throughout the high-altitude areas of PNG. According to Abasi et al. (2009), white clover is a highly nutritive pasture (Table 2) that is used in most grazing systems due to its ability to fix atmospheric nitrogen. Kikuyu is quite palatable and has a high protein content of 23 – 25 % (Table 2). It combines well with some legume grass species and its integration with white clover increases its utilization (Fukumoto & Lee, 2003; Fulkerson et al., 2007). However, both pasture species have considerably high crude fibre levels (10 – 20 %).

Day-old birds were raised in confinement and fed a Flame® starter ration (Lae Feed Mills (LFM) Pty Ltd) from 0 – 6 weeks-old before switching to a Flame®

pullet grower ration from 7-18 weeks-old (Table 2). All birds, with mean weights of 1.69 kg (b^{-1}), were then introduced to the two rearing systems and fed a Flame® egg layer ration over a 10-week period (18-28 weeks-old); which include a two-week adaptation period. The starter and grower rations were fed as crumbles while the layer ration was offered as pellets. Clean water was provided *ad libitum* throughout the experimental period.

Table 2. Nutrient specifications and energy content of LFM starter, grower, and layer rations (including kikuyu and white clover pastures).

Nutrient	Starter	Grower	Egg layer	Kikuyu	White clover
Dry matter (%)	89.8	91.5	89.8	25.0	98.6
Ash (%)	9.81	5.7	12.9	9.5	9.77
Crude fibre (%)	4.1	4.2	4.6	20.9	10.32
Fat (%)	7.7	3.9	5.6	2.9	--
Crude protein (%)	21.0	15.3	14.5	24.8	15.8
Calcium (%)	1.26	--	2.7	0.39	1.10
Phosphorus (%)	0.70	--	0.4	0.29	0.32
Nitrogen free extract (%)	47.19	--	36.9	40.8	--
Metabolizable energy (MJ, kg^{-1})	12.13	--	11.6	9.2	10.5

Adapted from Abasi et al., 2009, Kiraz, 2011, Glatz et al., 2013 and Ahizo et al., 2015.

The conventional production system involved keeping laying-hens fully confined and offering the layer ration *ad libitum*. The same diet was also fed to hens raised in the pasture-based production system but at a 50 % restriction level to determine whether these hens can be able to compensate for this reduction through herbage intake. Using the pasture-poultry system described by Salatin et al. (2006), laying-hens under this regime were provided daily outdoor-access (8 h, d^{-1}) to kikuyu-white clover pasture. Birds were allowed to forage on pasture using portable pens built from timber; each pen has a floor area of 3 m^2 and height of 0.75 m. All mobile pens were enclosed with mesh wire and shade cloth to avoid predation and direct sunlight exposure. More importantly, these pens were frequently moved to fresh pasture to ensure laying-hens had adequate access to forage.

Data collection, sorting, and analysis

Data on feed conversion, egg production and feed costs were recorded over the initial 56 days of the laying-phase. Feed offered and residuals were weighed daily while body weights of hens were recorded weekly using a kitchen-scale (10 kg ± 0.025 kg). Eggs produced were tallied and weighed daily with a smaller kitchen-scale (5,000 g ± 1 g). Eggshell thickness was measured with a Vernier calliper (200 mm ± 0.02 mm) while egg yolk colour was visually assessed using the Roche® Yolk Colour Fan. Data on feed intake and conversion, weight gain, egg production, egg weights and eggshell thickness were sorted using MS Excel® 2007 version. Weight gain and final body weights were derived as daily weight differences of birds and end weights at conclusion of the trials accordingly. Daily feed intake (DFI), feed conversion ratio (FCR), hen-day-egg production (HDEP) and benefit-cost ratios were determined using the equations below.

1) $\text{DFI (g)} = [\text{feed offered}] - [\text{feed residual}]$
2) $\text{FCR}_{\text{(egg weight)}} = \dfrac{\text{Feed consumed (g)}}{\text{Egg produced (g)}}$
3) $\text{HDEP (\%)} = \left(\dfrac{\text{Total no. of eggs produced on a day}}{\text{Total no. of hens present on a day}}\right) \times 100$
4) $\text{Benefit-cost ratio} = \dfrac{\text{Total returns (PGK)}}{\text{Total costs (PGK)}}$

All data was subjected to a one-way analysis of variance in GenStat® Release 4.2 (Lawes Agricultural Trust, 2005). DFI, FCR, HDEP and benefit-cost ratios were considered as dependent variables while rearing system was treated as the independent variable. The least significance difference of means test at 5 % alpha level was used for means separation.

RESULTS

Feed intake, feed conversion, and egg production

Daily feed intake (99.7 g, b^{-1} vs.123.9 g, b^{-1}; $P<0.05$), feed conversion ratio (1.89 vs. 2.22; $P<0.05$) and the number of eggs produced daily (10 vs.11; $P<0.05$) were significantly lower ($P<0.05$) for laying-hens raised on pasture compared to conventional-hens. Likewise, HDEP levels recorded over the study period differed considerably with pasture-hens attaining a lower HDEP (80.8 % vs. 90.2 %; $P = 0.015$) than laying-hens kept in confinement (Table 3).

Body weights, egg weights, and production costs

Similarly, live body weights of laying-hens at end of the study period (1.76 kg, b^{-1} vs.1.91 kg, b^{-1}; $P<0.05$), daily weight gain (2.24 g, b^{-1} vs. 6.43 g, b^{-1}; $P<0.05$), egg weights (52.9 g, egg^{-1} vs. 55.9 g, egg^{-1}; $P<0.05$) and cost per egg (PGK0.40 vs. PGK0.45; $P<0.05$) for pasture-hens were significantly lower than conventional-hens. However, benefit-cost ratios attained by pasture-hens were relatively better (1.74 vs. 1.57; $P=0.032$) compared to conventional-hens.

Eggshell thickness and yolk colour

While observations in this study showed eggshells from pasture-hens to be thicker than eggshells from conventional-hens, these variations were not significant (0.48 mm vs. 0.46 mm; $P = 0.232$). Yolk colour for all eggs observed in this study ranged from values 7 to 13 on the Roche® yolk colour scale (Figure 1).

Table 3. Effect of rearing system of Hy-line Brown laying-hen performances and benefit-cost ratios

	Raising system		*Significance*		
Parameter	**Conventional**	**Pasture**	**S.E.M**	***F* pr.**	**CV (%)**
DFI (g, b^{-1}, d^{-1})	123.9^a	99.7^b	3.12	0.002	5.6
FCR (kg, kg^{-1})	2.22^a	1.89^b	0.06	0.009	6.1
Eggs laid (d^{-1})*	11.0^a	10.0^b	0.24	0.015	4.6
HDEP (%)	90.2^a	80.8^b	1.96	0.015	4.6
Egg weight (g, egg^{-1})	55.9^a	52.9^b	0.48	0.005	1.8
Egg shell thickness (mm)	0.46^a	0.48^a	0.01	0.232	3.9
Body weight (kg, b^{-1})**	1.91^a	1.76^b	0.02	0.001	4.2
DWG (g, b^{-1})	6.43^a	2.24^b	0.53	0.001	24.5
Cost (PGK, egg^{-1})	0.45^a	0.40^b	0.01	0.035	5.8
Benefit-cost ratio	1.57^a	1.74^b	0.04	0.032	5.3

Within-row means bearing different superscripts (a, b) differ significantly ($P<0.05$). HDEP = hen-housed egg production. *Average number of eggs produced daily by 12 hens. **Mean body weight at end of study period i.e., at 28 weeks-old.

Egg yolk colour was positively influenced by herbage intake. Around 90 % of yolks from eggs produced by pasture-hens were deeply hued and varied between the values 11 and 13. In comparison, 70 % of egg yolks from conventional-hens vary from orange to pale yellow and ranged between values 8 and 9.

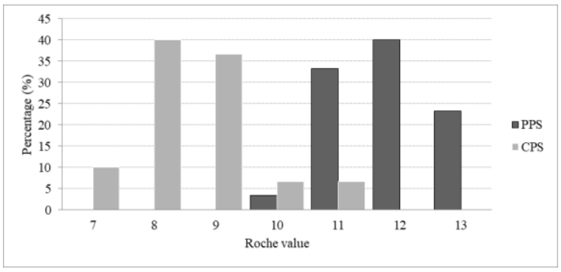

Figure 1. Effect of rearing system on egg yolk colour using the Roche® Yolk Colour Fan (PPS = pasture-production system, CPS = conventional production system).

DISCUSSION

Feed intake, feed conversion, and HDEP

Laying-hens subjected to the pasture-production system did not respond well as indicated by low feed intake, low HDEP, and low egg weights. These outcomes were as anticipated and are reflective of the 50 % feed restrictive regime for pasture-hens. Despite this, pasture-hens attained better FCRs than conventional-hens; pasture-hens were able to convert feed efficiently but were not able to fully compensate for the 50 % feed restriction program. This suggests that the 50 % feed restriction regime is excessive and needs to be reduced.

Although pasture-hens were efficient converters of feed, the number of eggs laid and subsequent HDEP levels were lower than conventional-hens. Mugnai et al. (2009) and Leenstra et al. (2014) also reported low egg production levels and low egg weights for laying-hens reared with outdoor-access to pasture. In this study, pasture-hens were observably very active in the outdoor environment. Hence, as explained by Glatz et al. (2005) and Miao et al. (2005) this increase in activity often lead to diversion of feed energy and poor egg production. Pasture-hens spent more time and energy scavenging, thereby utilizing dietary energy including energy reserves for mobility and less energy is allotted towards egg production.

The low egg production levels for laying-hens kept via pasture-based systems could be influenced by herbage consumption. According to Singh & Cowieson (2013) subjecting hens to pasture-based systems often lead to reduced feed consumption and dilution of protein and energy levels due to pasture intake. Moreover, De Vries (2015) reported that high fibre in poultry diets can have a negative influence on energy availability and interfere with the digestive function. The high fibre levels of kikuyu and white clover (Table 2) may have been influential in reducing feed intake and subsequent egg production. Nevertheless, Jha & Mishra (2021) reasoned that adequate fibre in poultry diets are also beneficial in maintaining gut health. Since hens reared under pasture-based systems consumed varying levels of pasture their production levels also differ according to pasture species and herbage intake (Mugnai et al., 2009; Kop-Bozbay et al., 2021).

Production costs

Despite attaining lower HDEP levels, pasture-hens achieved benefit-costs ratios that were reasonably more economical than conventional-hens. Similar assessments were reported by Miao et al. (2005) especially in keeping poultry under pasture-based rearing systems. This is important as low-resourced farmers could choose to restrict feed offered to pasture-hens and still achieve reasonable rates of return. For instance, this study showed that while egg production levels from pasture-hens were low, these eggs were cheaper to produce than eggs from conventional-hens.

More importantly, substituting certain portions of conventional feed, 50 % as shown here with high quality forages reduced operational feed costs; a similar view was also expressed by Fukumoto (2009). Yet, this study also demonstrated that pasture-hens were unable to fully make up for the 50 % feed restriction through herbage intake. Inferences from studies by Leenstra et al. (2014), Mugnai et al. (2009), and Miao et al. (2005) reported varying rates of bird mortality for laying-hens reared under pasture-based systems. In contrast, no mortalities were recorded over the duration of this study, regardless of production system. These differences could be attributed to variations across laying-hen genotype, pasture species, and geographical location.

Eggshell thickness and yolk colour

Eggshell thickness is one of the major egg quality traits and is influenced by several factors including breed, feed, and production environment (Miao et al., 2005). Mugnai et al. (2009) observed eggshells from hens raised with outdoor access to be thicker than eggshells from hens kept in confinement. Similarly, in this study, eggshells from pasture-hens were slightly thicker than eggshells from conventional-hens. This could be due to ingestion of grit during foraging and higher synthesis of vitamin D_3 because of greater exposure to sunlight (Bar et al., 1999). According to Hamilton et al. (1979) thicker eggshells are an important aspect of quality as economic losses associated with cracked or damaged eggs account for up to 8 % of production losses. Moreover, cracked, or damaged eggs provide a pathway for bacterial penetration. In contrast, intact eggshells are seen as important for table-eggs or for hatching as it protects the embryo from infections (Ketta & Tůmová, 2018).

Colour also plays a very important role in the consumers' perception of food and is also a key aspect of quality. According to Ponsano et al. (2004), colour does not influence nutritional properties but plays a role in a consumer's decision to buy. Additionally, consumers often associate colour with taste, freshness, and nutritional value. The yolk colour of eggs laid by pasture-hens was positively influenced by pasture intake. Consequently, 90 % of eggs produced by pasture-hens were deeply hued and were between the values 11 and 13 on the Roche® yolk colour chart. In comparison, 70 % of eggs from conventional-hens have yolk colour values that ranged from 8 to 9. Generally, egg yolks from pasture-hens were mostly orange to deep-orange while egg yolks from conventional-hens vary between pale yellow and orange. While some consumers favour deeply hued yolks because of its perceived superior sensory attributes and quality (Beardsworth & Hernandez, 2004; Bovskova et al., 2014), others may prefer otherwise. Nevertheless, where deeply hued yolks are preferred, pasture-based rearing systems can provide this requirement in place of commercial colouring.

CONCLUSION

Raising laying-hens on pasture and restricting conventional feed at 50 % did not improve egg production. However, the benefit-cost analysis suggests that this rearing system is cost effective and offers a genuine alternative to the conventional method. Similar studies on raising laying-hens, including local or crossbred genotypes, via pasture-based production systems are needed to ascertain its long-term potential and economic viability. Moreover, laying-hens raised on pasture were not able to fully compensate for the 50 % feed restriction regime used in this study. Hence, additional work involving different levels of feed restriction, particularly 30 – 40 % for hens raised under pasture-based systems is needed.

ACKNOWLEDGEMENT

The funding support from the NARI Research and Publications Committee is fully acknowledged.

REFERENCES

ABASI K, M, TAHIR, M, M, SHAH, H, A & BATOOL, F. 2009. Mineral Nutrient Composition of different Ecotypes of white clover and their nutrient credit to soil at Rawalakot Azad Jammu and Kashmir. *Pakistani Journal of Botany*, **41** (1): 41-51

AHIZO, J, AMBEN, S, ROBERT, A, BESARI, F, PANDI, J, KOHUN, J, P & GLATZ, C, P. 2015. Feed Conversion and Growth of Broiler Chickens fed Cassava blended with a Universal Concentrate diet during the finishing-phase: an on-farm study in Jiwaka Province, Papua New Guinea. *Journal of South Pacific Agriculture*, **18** (2):22-26.

AHIZO, J, AYALEW, W, KOBILA, K, PALAU, W & GLATZ, C. P. 2017. Egg production performance of two crossbred strains of hen (Australorp × Shaver Brown and Shaver Brown × Hyline Brown) fed on concentrate blended with cassava, in Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp.200-206.

AYALEW, W. BESARI, F, PANDI.J, & GLATZ, C. P.2017. Evaluation of the performance of broiler chickens fed mashed or milled formulations of sweet potato-based finisher diets in an on-station trial in Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp.208-213.

BAR, A., VAX, E., & STRIEM, S., 1999. Relationships among age, eggshell thickness and vitamin D metabolism and its expression in the laying hen. *Comparative Biochemistry and Physiology*, **123:**147-154.

BARTLETT, R, J., LILES, M, K & BECKFORD, C, R.2015. Comparing the Effects of Conventional and Pastured Poultry Production Systems on Broiler Performance and Meat Quality. *Journal of Agriculture and Life Sciences*, **2** (1):2375 – 4222.

BEARDSWORT, P.M., & HERNANDES J.M. 2004. Yolk colour – an important egg quality attribute. *International Poultry Production*, **12** (5): 17–18.

BESARI, F, DANBARO, G, SOLOMON, E, AYALEW, W, GLATZ, C, P, PANDI, J & KOHUN, J, P.2017a. Egg production performance of village hens fed on concentrates blended with sweet potato or cassava in Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp.175-181.

BESARI, F, DANBARO, G, AYALEW, W, PANDI, J & GLATZ, C, P.2017b. Egg production performance of Hy-line Brown hens fed on concentrates blended with sweet potato or cassava in the highlands of Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp182-187.

BOGOSAVLJEVIC-BOSKOVIC, S, RAKONJAC, S, DOSKOVIC, V & PETROVIC, D, M.2012. Broiler rearing systems: a review of major fattening results and meat quality traits. *World's Poultry Science Journal*, **68** (2): 217-228.

BOVŠKOVÁ, H, MÍKOVÁ, K & PANOVSKÁ, Z.2014. Evaluation of Egg Yolk Colour. *Czech Journal of Food Science*, **32** (3): 213-217.

CHEN, X, JIANG, W, TAN, H, Z, XU, G, F, ZHANG, B, X, WEI, S & WANG, Q, X. 2013. Effects of outdoor access on growth performance, carcass composition, and meat characteristics of broiler chickens. *Poultry Science*, **92**: 435-443.

DE VRIES, S. 2015. Fibre in Poultry Nutrition: Bonus or Burden? In: *20th European Symposium on Poultry Nutrition*. Prague, Czech Republic, 24-27 Aug. 2015

DOZIER, W. A., LOTT, B. D., & BRANTON, S. L. 2005. Growth responses of male broilers subjected to increasing air velocities at high ambient temperatures and a high dew point. *Poultry Science*, **84** (6), 962–966.

FANATICO, A. C., CAVITT, L. C., PILLAI, P. B., EMMERT, J. L., & OWENS, C. M. 2005. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Meat quality. *Poultry Science*, **84** (11), 1785–1790.

FANATICO, A. C., PILLAI, P. B., EMMERT, J. L., GBUR, E. E., MEULLENET, J. F., & OWENS, C. M. 2007. Sensory Attributes of Slow- and Fast-Growing Chicken Genotypes Raised Indoors or with Outdoor Access. *Poultry Science*, **86** (11), 2441–2449.

FUKUMOTO, K, G. 2009. Small-scale Pastured Poultry Grazing for Egg Production. University of Hawai, College of Tropical Agriculture and Human Resources, Livestock Management. LM-20, [Online]. Available at: ctahr.hawaii.edu/oc/freepubs/pdf/lm-20.pdf [Accessed 29 Mar. 2022].

FUKUMOTO, K. G., & LEE, C. N. 2003. Kikuyu grass for forage. College of Tropical Agriculture and Human Resources: LM-5.

FULKERSON, W. J., NEAL, J. S., CLARK, C. F., HORADAGODA, A., NANDRA, K. S., & BARCHIA, I. 2007. Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. *Livestock Science*, **107** (2): 253–264.

GLATZ, C, P., AYALEW, W., BLACK, I., PANDI, J., DEKLIN, J., MAZI M., DOM, M., BESARI, F., INGERSOL R., GEE, C., NEUMEIER, K., KAUPA, A., MARI, A., KERUA, W., KEOKA, B., DANBARO, G., MANUS, P., MAIP, D., VIRA, H., DOWA, E., OMOT, N., KOHUN, P & SOLOMON, E. 2013. Improving the profitability of village broiler production in PNG. 2013. Final Report 2013-33 for Project ASEM/2005/094, Australian Centre for International Agricultural Research (ACIAR): Canberra.

GLATZ. C, P. 2007. Poultry Feeding Systems in PNG. A report for the Australian Centre for International Agricultural Research (ACIAR). ACIAR Project No LPS/2001/07, ACIAR: Canberra.

GLATZ, C, P., RU, Y, J., MIAO, Z, H., Wyatt, S, K., & RODDA, J, B.2005. Integrating Poultry into Crop and Pasture Farming System. *International Journal of Poultry Science*, **4** (4): 187-191.

HAMILTON, R. M. G., HOLLANDS, K. G., VOISEY, P. W., & GRUNDER, A. A. 1979. Relationship Between Egg Shell Quality and Shell Breakage and Factors that Affect Shell Breakage in the Field–A Review. *World's Poultry Science Journal*, **35** (3), 177–190.

HANSON, L.W., ALLEN, B.J., BOURKE, R.M. & McCARTHY, T.J. 2001. Papua New Guinea Rural Development Handbook. The Australian National University, Canberra.

HUSSAIN, M, REHMAN, U, A, & KHALID, F, M. 2012. Feeding value of guar meal and the application of enzymes in improving nutritive value for broilers. *World's Poultry Science Journal*, **68** (2): 253-268.

HUSAK, R. L., SEBRANEK, J. G., & BREGENDAHL, K. 2008. A survey of commercially available broilers marketed as organic, free-range, and conventional broilers for cooked meat yields, meat composition, and relative value. *Poultry Science*, **87** (11), 2367–2376.

INCI, H, OZDEMIR, G, SOGUT, B, SENGUL, Y, A, SENGUL, T & TAYSI, R, M. 2016. Comparison of growth performance and carcass traits of Japanese quails reared in conventional, pasture, and organic conditions. *Revista Brasileira de Zootecnia*, **45** (1):8-15.

JACK, A. H. 2014. Feeding strategies to alleviate the effect of heat stress on growth performance in broilers. Massey University, Manwatu, New Zealand, [Online]. Available at:

https://mro.massey.ac.nz/handle/10179/6850 [Accessed 29 Mar. 2022].

JHA, R., & MISHRA, P. 2021. Dietary fibre in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: a review. *Journal of Animal Sciences and Biotechnology*. **12** (51): 1 – 16.

KETTA, M., & TŮMOVÁ, E. (2018). Relationship between eggshell thickness and other eggshell measurements in eggs from litter and cages. *Italian Journal of Animal Science*, **17** (1), 234–239.

KIRAZ, A. B, 2011. Determination of Relative feed value of some Legume hays harvested at flowering stage. *Asian Journal of Animal and Veterinary Advances*, **6 (**5):525-530.

KOP-BOZBAY, C., AKDAG, A., BOZKURT-KIRAZ, A., GORE, M., KURT, O., & OCAK, N. (2021). Laying Performance, Egg Quality Characteristics, and Egg Yolk Fatty Acids Profile in Layer Hens Housed with Free Access to Chicory- and/or White Clover-Vegetated or Non-Vegetated Areas. *Animals: An Open Access Journal from MDPI*, **11** (6): 1708.

LAWES AGRICULTURAL TRUST. 2005. GenStat, Release 4.2, Discovery Edition. VSN International Ltd: Hampstead, United Kingdom.

LEENSTRA, F, MAURER, V, GALEA, F, BESTMAN, M, AMSLER-KEPALAITE, Z, VISSCHER, J, VERMEIJ, I & VAN KRIMPEN, M. 2014. Laying hen performance in different production systems; why do they differ and how to close the gap? Results of discussions with groups of farmers in The Netherlands, Switzerland and France, benchmarking, and model calculations. *European Poultry Science*, **78**: 1 -10.

LILES, K, M, BARTLETT, J, R, & BECKFORD, C, R. 2015. Comparing the Effects of Conventional and Pastured Poultry Production Systems on the Stress Levels of Broilers, *Professional Agricultural Workers Journal*, **2** (2): 1-10.

MAKKAR, H, P, S.2006. Improving animal productivity through meeting nutrient deficiencies with multi-nutrient blocks, enhancing utilization efficiency of alternate feed resources, and controlling internal parasites: a summary. In IAEA (ed.) Improving animal productivity by supplementary feeding of multi-nutrient blocks, controlling internal parasites, and enhancing utilization of alternate feed resources. Animal Production and Health Section, International Atomic Energy Agency: Vienna, Austria, pp.1-9.

MIAO, H, Z, GLATZ, C, P & RU, J, Y. 2005. Free-range poultry production- A Review. *Asian-Australasian Journal of Animal Science*, **18** (1):113-132.

MUGNAI, C, DAL BOSCO, A & CASTELLINI, C. 2009. Effect of rearing system and season on the performance and egg characteristics of Ancona laying-hens. *Italian Journal of Animal Science*, **8** (2): 175-188.

NANO, E, W.2015. Performance of broiler chickens fed copra meal and cassava chip meals in free choice feeding system. *Journal of South Pacific Agriculture*, **18** (2):27-35.

PANDI, J, AYALEW, W., AND GLATZ, P.2017. Evaluation of the performance of broiler chickens fed diets containing 50% cassava or sweet potato in farmer trials in Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp.221-228.

PONSANO, E. H. G., PINTO, M. F., NETO, M. G., & LACAVA, P. M. 2004. Rhodocyclus gelatinosus Biomass for Egg Yolk Pigmentation. *Journal of Applied Poultry Research*, **13** (3), 421–425.

SALATIN, J., DUNAWAY, H. V., & SALATIN, W. T. 2006. Pasture Poultry Profits [Online]. Available at: https://bookcenter.club/?book=0963810901# [Accessed 30 May. 2022].

SINGH, M., & COWIESON, J.A.2013. Range use and pasture consumption in free-range poultry production. *Animal Production Science*, **53**: 1202 – 1208.

SOLOMON, E, KOHUN, J, P, AYALEW, W & GLATZ, C, P. 2017. Evaluation of the growth performance of broiler chickens fed a rice bran-based finisher diet in an on-station trial in Papua New Guinea. In: GLATZ, C, P (ed.) Local feed resources for pig, poultry, and fish production in Papua New Guinea. Australian Centre for International Agricultural Research: Canberra, ACT, pp.214-220.

SOLOMON, E, LOBAO, M, DOM, M, PANDI, J & GLATZ, P. 2016. Performance of broilers fed a universal protein concentrate blended with cassava root meal as a finisher ration in Papua New Guinea. *Journal of South Pacific Agriculture*, **19** (1 & 2):1- 8.

SOSSIDOU, N, E, DAL BOSCO, A, ELSON, A, H & FONTES, M, C.2011.Pasture-based systems for poultry production: implications and perspectives. *World's Poultry Science Journal*, **67** (1):47-58.

WANG, H, K, SHI, R, H, DOU, C, T & SUN, J, H. 2009. Effect of a free-range raising system on growth performance, carcass yield, and meat quality of slow-growing chicken. *Poultry Science*, **88**:2219-2223.