# Selection strategies to improve the production potential of layer chicken in Thailand

by

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# Declaration

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I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used have been acknowledged in this thesis.

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# Abstract

This thesis explores the options to genetically improve the performances of the layer chicken produced by the Department of Livestock Development for small scale commercial layer operations in Thailand. To fulfill this objective, the genetic parameters were estimated for five economically important traits; age at first egg (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), total number of eggs up to 17 weeks of lay (EN) and average egg weight at the 17$^{th}$ week of lay (EW). A total of 11,195 hen records from 652 sires and 3,892 dams were used to estimate genetic parameters for the five traits from two purebred lines, Rhode Island Red (RIR), White Plymouth Rock (WPR) and two hybrid lines, RC and WC, generated by crossing RIR and WPR to a commercial strain.

Fixed effects of year and hatch within year were significant ($P \leq 0.05$) for all traits. Direct additive genetic effects were significantly influencing all traits with moderate heritabilities estimated for all five traits in all four lines. Estimated heritabilities for AFE, BWT, EWFE, EN and EW were 0.45, 0.50, 0.29, 0.19 and 0.43 for RIR; 0.44, 0.38, 0.33, 0.20 and 0.38 for WPR; 0.37, 0.41, 0.38, 0.18 and 0.36 for RC; and 0.46, 0.53, 0.36, 0.38 and 0.45 for WC, respectively. Maternal effects were significant for EN and EW in RIR and BWT and EW in WPR. Positive genetic correlations were estimated between AFE and all other traits, except for EN, in all four lines. The EN was negative correlated with the other traits in all four lines, except with BWT in RC (0.04) and AFE and BWT in WC (0.06 and 0.19).

Economic weights were derived for RC and WC lines by using a bio-economical production model. Economic weights were -$0.06/day (AFE), -$0.57/kg (BWT), $0.23/% for rate of lay (RL), 0.18/g (EW), and 0.20/% for survival ability (SUR). Fluctuation in feed costs and egg prices influenced the derived economic weights. A multi-trait selection index was used to predict genetic response and profit in a small scale commercial poultry production system comparing a strategy with the same breeding objectives for both lines with a strategy where the breeding objectives were different using different traits in male and female lines. Using the same breeding objectives in male and female lines gave a higher profit ($3.92) than using different traits ($3.45). However, this scenario needs to be re-evaluated after a few generations of selection to examine the influence of selection on traits means, heterosis and genetic correlations between traits and thereby on the efficiency of the selection strategy.

## Chapter 3

Tongsiri, S., Jeyaruban, M., & Van Der Werf, J. (2015). Genetic parameters for egg production traits in purebred and hybrid chicken in a tropical environment. British Poultry Science, 56(6), 613-620. doi: 10.1080/00071668.2015.1099614

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# Abbreviations

BREEDS OF LAYER CHICKENS

RIR Rhode Island Red

WPR White Plymouth Rock

RC Rhode Island Red crosses with a commercial line

WC White Plymouth Rock crosses with a commercial line

COM Commercial layer line

ECONOMIC TRAITS

AFE Age at first egg

BWT Body weight at first egg

EWFE Egg weight at first egg

EN Egg number

RL Rate of lay

EW Average egg weight at $17^{th}$ week of lay

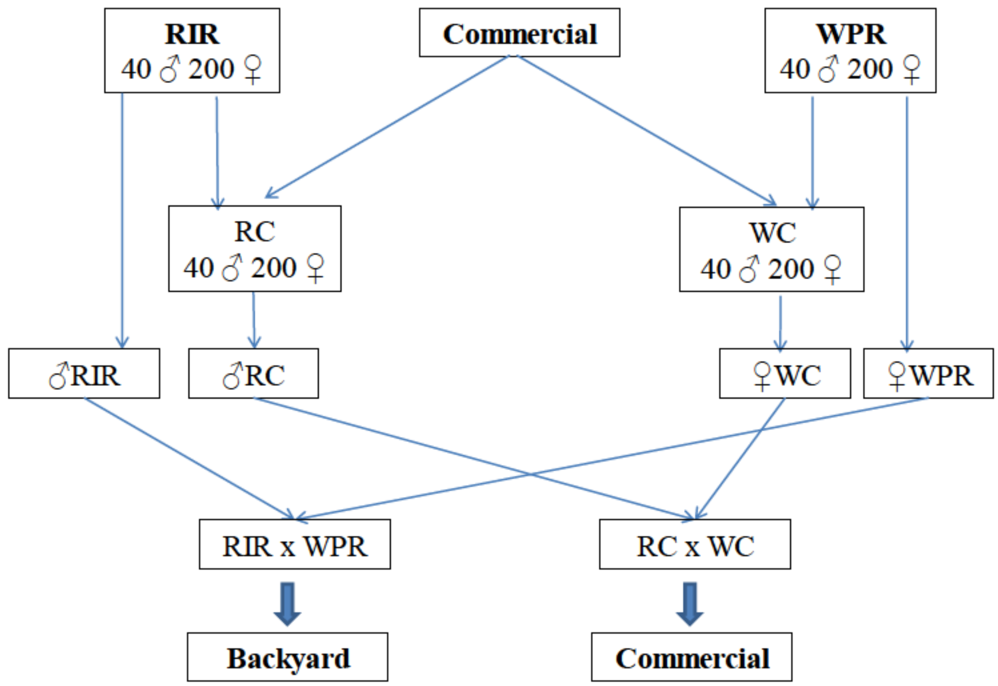
SUR Survival rate

# Chapter 1. General Introduction

## 1.1. Introduction

The layer chicken industry is an important sector of livestock in Thailand. Backyard egg production started in the beginning of 19th Century. Adapted local poultry breeds such as Bantum and Batong were used in the backyard poultry production. However, their productivity was not sufficient to sustain the household income and protein source in the rural areas. Therefore, from 1924, exotic poultry breeds and strains were imported to Thailand to improve the egg production in the commercial poultry farms. White Leghorn strains were imported in 1924, followed by Rhode Island Red, White Plymouth Rock, and New Hampshire in 1949 and a layer chicken crossbreeding program was initiated in 1951. Currently, the contribution of intensive poultry production and backyard production to the total egg production in Thailand is about 90% and 10%, respectively (Heft-Neal et al., 2008).

In 2003, the Department of Livestock Development (DLD) in Thailand initiated a layer poultry improvement program to improve the layer productivity. The main objective of this project is to develop layer chickens with the ability of high egg production and high survivability under harsh conditions in Thailand. Pure lines of Rhode Island Red (RIR) and White Plymouth Rock (WPR) were established. The RIR and WPR were crossed with an imported commercial layer strain to establish two new crossbred lines, namely RC and WC. WPR and WC are the female lines because of their sex linked feather sexing ability and the RIR and RC are the male lines. The day old chicks are issued to small holder farms by crossing the RIR and WPR lines, and RC x WC crosses are issued to commercial farms.




**1-1Breeding program to develop DLD chickens**

About 200 laying hens per year are maintained in each line. The replacement birds in each line are selected based on an index, using age at first egg (AFE), bodyweight at first egg (EWFE), egg weight at first egg (EWFE) number of egg produced the first 120 days of lay (EN), and average egg weight at 17 weeks of age (EW17). Currently, all four 4 parent stock lines are using the same index. This means there is no differential selection for the males and female lines. This is mainly due to lack of experts in poultry breeding. Moreover, the same selection index is used commercial and the backyard chicken lines, mainly due to lack of estimated genetic parameters for the different poultry lines.

## 1.2. Objective of this thesis

The objective of this research is to develop a selection strategy or strategies for the layer lines with the aim of improving the layer productivity under commercial and backyard poultry production systems in Thailand. This will be achieved by estimating genetic parameters for economically important traits in the parental lines. Economic values of the various traits in the commercial production system will be derived to develop economic breeding objectives for the RC and WC layer lines in Thailand. The economic value of traits will be used in multi-trait selection indices to use as selection tool for selecting the male and female lines. This is to improve the egg productivity in the crossbred population of the commercial environment.

Chapter 2 provides an overview of poultry production systems and the poultry breeding structures in Thailand. Furthermore, it describes the different productivity potentials of various breeds, strains and their crosses and describes opportunities and constraints for poultry production in Thailand. This chapter also reviews the literature and summarizes heritabilities ($h^2$) and genetic correlations ($r_G$) for economically important egg production traits. Furthermore, the principle of determining breeding objectives is discussed and estimates from literature of economic values and for predicted selection responses from implementing selection index approaches to improve egg production are summarized.

Genetic parameters for five economically relevant egg production traits that are currently recorded in all four lines is explored in chapter 3. Over ten thousands egg production records from two pure lines and two hybrid lines selected for 10 generations were used to estimate heritabilities and genetic correlations for age at first egg (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), total number of eggs up to 17 weeks of lay (EN) and average egg weight at 17$^{th}$ week of lay (EW). Heritabilities and genetic correlations were estimated by using the Residual Maximum Likelihood (REML) method. The best model was identified for each trait in the univariate analysis and was subsequently used to estimate the genetic and phenotypic correlations between the five egg production traits.

Five economically important traits for small scale commercial layer production were identified and the marginal returns on profit by changing those via genetic improvement were calculated using the principles of bio-economic modelling in chapter 4. The derived economic values were derived for a small scale commercial poultry production system with varying feed, labour and management costs. Identified economic values were combined into three sets of selection indices to predict responses to index selection. In set one, the same selection index comprising all five traits were applied to both hybrid lines, using the same economic weights for those traits in each line. In set two, AFE, RL and SUR were included in a selection index for the female line (WC) and in set three, BWT, EW and SUR were included in the selection index for the male line (RC).

Sets two and three were developed with the aim of improving egg number and survival in the female line and egg weight and survival in the male line. Responses to selection in trait means and in monetary terms were compared for using the same index versus different selection indexes for divergent selection in male and female lines.

Chapter 5 provides a general discussion of this thesis. It discusses estimated genetic parameters for five economically important traits measured under temperate and tropical climates. It also discusses differences in the response to selection and profits realized by using the same or different breeding objectives in male and female lines.

# Chapter 2. Literature Review

## 2.1. Egg production in the world

The world egg industry is changing. The main commercial poultry producers have shifted their grandparent and parent lines from the United States and countries in Europe to developing countries. In the future, the developing countries will house most of the egg industry and produce the majority of eggs in the world .Windhorst (2011), predicted that egg production in developed countries decreased by 20% and increased by 200% in developing countries. According to an FAO statistic, in 2011, China was the biggest producer of eggs with 24 million tons of eggs. This was about 37% of total number of eggs processed in the world (Table 2-1). The next top four countries are the United States of America, India, Japan, and Mexico, in that order. Moreover, FAO and the International Egg Commission (IEC) were encouraging people to consume more eggs because eggs are high in nutrition, cheap, and easy to cook. Overall, the average egg consumption in the world has significantly increased in the last ten years with the per capita consumption of 8.1 kg in 2000 increased to 8.9 kg in 2009 (Food and Agriculture Organization of the United Nation, 2012). The high consumption has stimulated farmers in developing countries to increase their production level.

**Table 2-1 The top five egg-producing countries in 2011**

| Ranking | Country | Production (mil.ton) | Eggs (million) | Proportion in the world (%) |
|---|---|---|---|---|
| 1 | China | 24 | 400,000 | 37 |
| 2 | USA | 5 | 90,000 | 8 |
| 3 | India | 3 | 60,000 | 5 |
| 4 | Japan | 2 | 40,000 | 4 |
| 5 | Mexico | 2 | 40,000 | 4 |

Source : Laughrugirasawat (2012).

### 2.1.1. Egg production systems in developing countries

Egg production systems in developing countries have gradually been upgraded from the traditional backyard poultry keeping to highly advanced commercial battery cage systems. Deep-litter systems were introduced between 1930 and 1950 to separate hens from their feces, and protect against parasite- and disease contamination. However, these systems led to hysteria, feather pecking, and cannibalism in laying hen. In the 1930s, the first commercial cage egg system was developed in the USA. Subsequently, the battery cage system became popular in Europe. Laying hens managed under free-range and semi-intensive houses were moved to battery cages because of low egg contamination, and easy management. The cage system was very popular from 1940 to 1990. In the last decade, with the higher demand for free-range eggs and outdoor organic eggs, the free-range system is gradually gaining popularity (Elson, 2004).

Currently, there are two main poultry production systems in South-East Asia. The first system is found in the commercial sector. It is a high intensive management, high input and high productivity system. The other system is the smallholder or traditional village poultry system. It relies on a low input and low outcome principle. The intensive farms house large number of layers in small area. Layer hens under intensive management usually stand in battery cages. For example, in Australia, intensive farms house about 500,000 laying hens on one farm in multiple-level cages (Poultry Hub, n.d.). Normally, the egg numbers per bird in intensive farms are higher than smallholder farms or free-range farms.

The smallholder system is mainly considered as a rural egg production system. It is an important system providing protein and generating income for rural people (Aini, 1990). There are about 500 million smallholder farms around the globe. Under this system, the birds are reared outside the field of "business" production (Kryger, Thomsen, Whyte, & Dissing, 2010). Rushton and Ngonngi (1998) classified smallholder farms into three types,

1) The scavenging system – a form of production characterized by very low inputs, with birds allowed to wander freely and scavenging for all or most of their food.
2) The free-range system – in which poultry are provided with some supplementary feed, and night-time housing.
3) The semi-commercial system – in which poultry are provided with feed and water and kept in fenced-in areas.

Eggs produced by free-range layers are preferred by “green” or “ethical” consumers. They prefer to buy the products that are perceived as not harmful to the environment and society (Gemma & Aikaterini, 2001). Under the typical free-range system, layer birds are introduced to the outdoors and allowed to free-range at 16 weeks of age and they may live up to 72 weeks of age. Birds are culled at 72 weeks of age (Marian, Paul, Mark, Katherine, & Amy, 2003). Egg production from the free-range system has increased in the last decade (Permin et al., 1999). Gueye (1998) reported that free-range poultry production increased by up to 80% in Africa.

Few studies have compared the economic efficiency of intensive and free-range systems. Hossain (1992) compared the economics of rearing three breeds of chickens under intensive and free-range systems in Bangladesh. He compared the egg production of Rhode Island Red (RIR), Barred Plymouth Rock (BPR), and indigenous (Desi) hens under intensive and traditional free-range systems. The egg production in the intensive farming system was higher than egg production on traditional farms for all three breeds, but the average egg weight from the two systems was similar. However, there were no feed costs for chickens on traditional farms, whereas the cost of feed for RIR and for BPR was 149 Taka and for Desi 134 Taka per day under the intensive farming system. Despite the inclusion of feed cost, the gross profit for RIR under intensive management (167 Taka) was higher than the gross profit for RIR under the traditional system.

## 2.2. Poultry production in Thailand

### 2.2.1. Poultry production systems in Thailand

In the early 19th century, the backyard poultry production system was very popular among poultry farmers in Thailand. They reared birds in the backyards of their houses. They used local chicken breeds such as Bantum, and Batong to produce eggs. In 1924, exotic breeds, such as Leghorn, were imported to increase egg production under the commercial farming system. In 1949, poultry breeds, such as Rhode Island Red, Australorp, Barred Plymouth Rock, White Plymouth Rock and New Hampshire were imported for research purposes. Currently, the layer chicken industry is an important sector of the livestock industry in Thailand.

The standard of commercial layer farms in Thailand is classified by the number of laying hens on the farm. The commercial layer farms are categorized into five farm standards (Phasang, 2010) as given below:

1) Very small farm means the number of laying hens is less than 10,000 birds.
2) Small farm means the number of laying hens is between 10,001 and 20,000 birds.
3) Medium farm means the number of laying hens is between 20,001 and 50,000 birds.
4) Large farm means the number of laying hens is between 50,001 and 100,000 birds.
5) Extra-large farm means the number of laying hens is more than 100,000 birds.

Commercial egg production in Thailand is based on the battery cage system. In this system, the day-old chicks are kept in brooders for three weeks after they hatch. Feed and water are provided ad libitum. At three weeks of age, the chicks are moved to deep litter houses until they reach the age of 16 weeks. The pullets, at the age of 16 weeks, are moved to cages or deep litter houses for laying. The birds are culled at 72 weeks of age. Litter, such as rice straw or wood dust, is used in floor housing to protect against egg breakage absorb some secretion, and to prevent bacterial contamination of the eggs.

Commercial poultry producers purchase their chicks as day-old or as two-month-old growers or as pullets at 16 weeks of age. Most farmers choose to buy day-old chicks as this is the most economical way to build their flock. However, there is a high risk of the mortality with day-old chicks and, therefore, famers need good management skills to raise them. Alternatively, farmers purchase two-month-old growers to start the layer production. The farmer will start rare layer birds from two months until laying period. This is a good option for farmers who are new to poultry management. It does not need high management skills and the cost of the birds and feed is relatively inexpensive. A third option is purchasing pullets at 16 weeks of age. This is a popular option in Thailand because it is easy and egg production begins almost immediately. However, the pullets are expensive and the farmers need to know their vaccination history and management practices (Thewarukpitak, 1993).

The layer production cycle lasts just over a year; about 52 – 56 weeks of egg production. Commercial farms often use an all-in and all-out system to manage their flocks. This is effective in controlling disease and it is an easy farm management practice. Eggs are graded into six categories a day after they are collected. The egg price depends on egg size and egg quality as shown in Table 2-2. The majority of the eggs produced in Thailand fall into the medium size category.

**Table 2-2 Egg weight classes for consumer grades and egg price in Thailand in 2012**

| Grade | Size | Weight class (g) | Price per egg (THB) |
|---|---|---|---|
| 0 | Jumbo | ›70 | 3.37 |
| 1 | Extra-large | 65 - 69 | 3.18 |
| 2 | Large | 60 - 64 | 2.94 |
| 3 | Medium | 55 - 59 | 2.83 |
| 4 | Small | 50 - 54 | 2.62 |
| 5 | Peewee | 45 - 49 | 2.52 |

Source: The Association of Hen Egg Farmers Traders and Exporters (2012). (1AUD = 31.5THB).

### 2.2.2. Chicken population in Thailand

The chicken population in Thailand varies across the years as shown in Table 2-3. There has been a significant increase in the total number of chickens raised in Thailand from 1998 to 2008. During this ten-year period, the number of chicken raised in Thailand increased from 155 to 235 million. Broiler chickens constitute the highest proportion (57.5%) of all the chicken raised in Thailand, followed by native (28%), and layer chickens (14.5%).

### 2.2.3. Egg production in Thailand

The layer and broiler industry in Thailand is one of the important household income-generation sectors in Thailand. In 2008, about 42% of the total value of livestock products in Thailand came from broiler and layer production. In 2012, there were 50,911 egg-producing farms in Thailand, and they housed 51 million egg-laying chickens. The layer farms accounted for 2.22% of the all poultry farms in Thailand and 13.51% of the total poultry population (Information Technology Center, 2013).

**Table 2-3 Size of chicken population in Thailand from 2000 to 2008**

| **Year** | **Chickens** | | | **Total (mil.)** |
|---|---|---|---|---|
| | **Broiler (mil.)** | **Laying Hen (mil.)** | **Native (mil.)** | |
| 2000 | 91 | 25 | 73 | 189 |
| 2001 | Not classified | | | 214 |
| 2002 | 146 | 25 | 57 | 228 |
| 2003 | 165 | 24 | 63 | 252 |
| 2004 | 102 | 21 | 56 | 179 |
| 2005 | 148 | 41 | 65 | 254 |
| 2006 | 100 | 30 | 54 | 184 |
| 2007 | 170 | 50 | 63 | 283 |
| 2008 | 137 | 41 | 57 | 235 |

Source: Information Technology Center (2013).

Since 2008, training has improved the management skills of the poultry farmers in Thailand and this, in turn, has increased the application of modern technologies, such as automatic feeding and watering, in routine management of poultry flocks. As a result, egg production in Thailand increased by 3.61% per year over the last ten years. Currently, farmers in Thailand produce about 37 million eggs per day. In 2013, Thai farmers produced 683,826 tonnes of fresh eggs (Office of Agricultural Economic, n.d.). The majority (95 – 99%) of the eggs produced in Thailand are used for local consumption. Since 2008, egg consumption has increased by 4.65% per year and the average egg price by 4.20% per year. Currently, farmers sell fresh eggs for about 2.55 THB (0.1AUD) each.

### 2.2.4. Import and export of eggs and egg products

Thailand exports egg and egg products to Hong Kong and African countries. About 80 to 90% of all exports are exported to Hong Kong and the rest are to Africa. Major export products are egg shell, liquid egg, liquid yolk, egg powder and albumin powder. The income generated from the export of eggs and egg products from Thailand is shown in Table 2-4. The export of eggs and egg products generate valuable foreign income for Thailand. From 2003 to 2009, the foreign income generated by exporting eggs and egg products increased significantly (Table 2-4). The export of eggshell constituted a significant proportion of the egg products exported.

**Table 2-4 The import and export value of egg products in Thailand, 2003-2009**

| Year | Layer (mil. Baht) | | Balance (mil. Baht) |
|---|---|---|---|
| | Import | Export | |
| 2003 | 110 | 608 | +498 |
| 2004 | No data | No data | No data |
| 2005 | 191 | 385 | +194 |
| 2006 | 198 | 490 | +688 |
| 2007 | 252 | 952 | +700 |
| 2008 | 182 | 1,164 | +982 |
| 2009 | 134 | 1,174 | +1,040 |

Source: Information Technology Center (2013).

### 2.2.5. Layer breeding in Thailand

Before commercial poultry production was initiated in 1924, backyard poultry keeping was a popular enterprise in Thailand. Thai people prefer brown eggs to white ones and like their eggs to be large with a red yolk. Therefore, the layer breeds or strains used in Thailand need to produce eggs with these characteristics. To achieve this, Rhode Island Red chickens from the United States and Australorp chickens from Australia were imported in 1949. Crossbred layer chickens were introduced in 1951 to increase the survival and productivity of backyard poultry in Thailand. Currently, poultry production is one of the important employment-generation sectors in Thailand. In 2007, there were 17,398 family-owned layer farms with 49 million layers (Information Technology Center, 2007).

### 2.2.6. Poultry genetic resources in Thailand

Exotic layer chicken genetic resources were introduced to Thailand through the gradual importation of exotic breeds and strains. Initially, farmers raised pure-bred layer chickens and then gradually changed to crossbred or commercial layer chickens as the availability of the latter increased. The crossbred birds have high egg productivity, and can survive under the harsh management conditions in Thailand (Sopha, Thummabood, & Srisuk, 2012). The basic layer chicken breeds in Thailand are Rhode Island Red (RIR), White Plymouth Rock (WPR), their crosses (DLD chicken) and some native chicken breeds.

#### *2.2.6.1. Characteristics of Rhode Island Red*

The RIR was developed from Asiatic black-red fowls of the Shanghai, Malay, and Java types. It was bred in Rhode Island Province and Red Java in the USA in 1860 (Groen, 2003). The original RIR had a rose comb. The Americans called this bird as "American Reds" because of this character. Later the name changed to Rhode Island Red. RIR chickens also became popular in Europe and other Asian countries due to their productivity and also their sex-linked feathering trait (Mack & Donald, 1990), which enhances the sexing of chick at the time of hatching. The dual purpose quality of RIR is advantageous for both the broiler and layer chicken industry. Their body is deep, broad and long. It has yellow skin, and red-brown feathers, except for the edge of the wings and the tail, which is black. They have a single comb and red ear lope. Their eggshell varies from light brown to dark brown. According to Animal Husbandry Division (2003) in Thailand, the RIR layers lay their first eggs at 172 (± 25) days after hatching and when they reach a body weight of 1,930 (± 181) grams. Average weight of their first egg is 36 (± 5) grams and they lay about 241 (± 25) eggs per year with an average egg weight of 55 (± 8) grams (Table 2-5) (Animal Husbandry

Division, 2003). In the past, RIR sex linkage nature of feathering was used to sex the one day-old-chicks (Mack & Donald, 1990).

#### *2.2.6.2. Characteristics of White Plymouth Rock*

The WPR is a chicken breed choice made for female lines in many chicken breeding programs (Leeson & Guelph, 2000). The benefit of using WPR hens in the layer industry is producing a day-old chick with easy sexing on the day of hatching (Mack & Donald, 1990). The body and wing feathers of WPR chicken are white. They are black barred on the edge of their wings, coral and tail. They usually have a single red comb, red ear lobes, and yellow skin and shank. Their eggs are light brown. White Plymouth Rock layers lay their first eggs at 166 (±24) days after hatching and when they reach the body weight of 1,837 (±172) grams. The average weight of their first egg is 35 (±5) grams and they lay about 220 (±21) eggs per year with an average egg weight of 55 (±7) grams (Table 2-5). In the last decade, White Plymouth Rock has been used as a broiler breed. However, their slow feathering ability is not suitable for broiler production.

#### *2.2.6.3. Characteristics of DLD*

The DLD bird is the new layer chicken breed in Thailand. It was bred by the Department of Livestock Development in Thailand by crossing the RIR, WBR, and a commercial strain to improve the protein consumption and household income of rural farmers in Thailand. Crossbred DLD chickens are able to survive and produce eggs under both harsh and intensive farming conditions in Thailand. The DLD phenotype includes brown feathers, yellow skin, a single comb, a red face and ear lobes. Their eggs are brown. The DLD layers lay their first eggs at 159 days after hatching and when they reach the body weight of 1,935 grams. The average weight of their first egg is 41 grams and they lay about 274 eggs per year with an average egg weight of 56 grams (Table 2-5).

The exotic breeds and their crosses perform better than the Thai indigenous chickens for age at first eggs, average number of eggs per year and average egg weight (Table 2-5). This demonstrates the importance of improved poultry strains to increase the layer productivity in Thailand.

**Table 2-5 Economic traits and means of Rhode Island Red, Barred Plymouth Rock, DLD chickens, and Thai indigenous birds under intensive management in Thailand**

| Economic Trait | RIR | BPR | DLD | Thai indigenous |
|---|---|---|---|---|
| Age at first egg, days | [a]172±25 | [a]166±24 | [a]159±7 | [b]187±16.7 |
| Body weight at first egg, g | [a]1,930±181 | [a]1,837±172 | [a]1,935±130 | [b]2,135± 246 |
| Egg weight of first egg, g | [a]36±5 | [a]35±5 | [a]41±3 | [b]43±6 |
| Average eggs/year | [a]241±25 | [a]220±21 | [a]274±20 | [b]147±13 |
| Average egg weight, g | [a]55±8 | [a]55±7 | [a]56±2 | [b]50±3.7 |

Source: [a]Animal Husbandry Division (2003), [b]Leotaragul, Morathop, and Sopha (2011).

### 2.2.7. Constraints for egg production in Thailand

Despite the increase in the number of layers and the number of eggs produced over the last decade, there are challenges for egg industry in Thailand.

A) Availability of high performance birds

The availability of layer breeds is the first constraint for poultry production in Thailand. The indigenous chickens are low in production and the exotic strains are expensive to maintain under the harsh climatic conditions in Thailand. Therefore, there is a need to introduce highly adaptable, high-producing poultry strains to the small-scale poultry producers in Thailand. The DLD chickens were developed to address this issue.

B) Disease

The occurrence of infectious diseases, such as Newcastle disease (ND), flow flock disease, infectious bronchitis disease (IB), and avian influenza (AI) have detrimental effects on the expansion of the poultry industry in Thailand. For example, in 2004, the poultry industry in Thailand was affected by Avian Influenza, AI ("bird flu"). This had a detrimental effect on the import and export of poultry products (Worasri, 2011). Infected hens had low productivity with normal feed consumption and, thereby, compounded the economic loss to farmers.

C) Feed cost

The cost of poultry feed and supplements also influence the profitability of layer farms. Feed cost is the biggest cost in egg production and amount to about 74% of the total cost. Furthermore, prices for feed ingredients in the world market are continuing to increase. This has a direct influence on the cost of production of eggs and egg products in Thailand.

D) Limited local demand

Existing market structures is another constraint that affects poultry production in Thailand. Low egg consumption in the diets of Thai people limits market demand for eggs and egg products in Thailand. Egg consumption of Thai people, in 2009, is lower than that of people in the ASEAN region. Per capita annual egg consumption of Thai, Malaysians, Japanese, Taiwanese and Chinese was 150, 220, 300, 300, and 300, respectively. The majority of Thai believe that excessive egg consumption may lead to health problems, such as coronary heart disease (CHD) and hypertension. Students consume a large proportion of eggs produced in Thailand. Therefore, the egg demand in the school vacation period is lower compared to those during school terms.

E) Uncontrolled importation

Uncontrolled importation of eggs and egg products also affect the layer industry in Thailand. Eggs and egg shells are imported at lower prices than the actual cost of production in Thailand. The average egg price for an imported and a locally produced egg in 2009 was 2.82 and 3.39 Baht Thai, respectively (Trade Policy and Strategy Office, 2012). Finally, fluctuation of egg prices leads to lack of confidence in the existing egg market in Thailand. The egg prices in Thailand fluctuate heavily over a short interval. Thai farmers find it difficult to adjust to the sudden market variations. In addition, smallholder farmers find it difficult to obtain adequate market share for their products.

The current agriculture policy is inadequate in controlling the importation of eggs and the fluctuating demand in of the market. In 2011, the number of layer chickens in Thailand increased due to the lack of control of the Egg Board of Thailand over the import of day-old chicks to Thailand. In 2011, 180,123 more day-old chicks were imported to Thailand than the previous year.

This led to the oversupply of eggs and egg products and resulted in lower prices for locally produced eggs and egg products.

Three major steps are needed to improve the layer industry in Thailand. Firstly, expanding the export market for eggs and egg products. Secondly, government initiative is required to improve the knowledge of layer farmers, increase the market share for small-scale poultry producers, control factors influencing egg production by introducing sound agricultural policies, and assure the supply of high-producing breeds or strains to local farmers. Thirdly, proper standards for layer farms and one-day-old chick producers need to be established to improve consumer confidence in local products. Furthermore, production potential of the newly developed DLD need to be improved to sustain the layer industry.

## 2.3. Genetic improvement

Genetic improvement is the science of applying genetic knowledge to improve the production potential of livestock and poultry. In genetic improvement, genetic capabilities of poultry breeds and strains are altered through within breed or within line selection and also by crossing of different breeds and lines.  Three main approaches to genetic improvements are:

### 2.3.1. Line breeding

Line breeding involves selecting birds within a line to secure the genetic makeup of identified superior males or females to improve economically important trait or traits (Thongthainun, 2009). Therefore, selection within a line is initiated by identifying superior males or females for a particular trait or traits and then crossing them with well-performing birds and also to the progeny from those crosses. This keeps the performance of the offspring close to their high-producing ancestors. Therefore, line breeding increases the homozygosity within a line and, thereby, results in more uniform progeny. This helps to sustain consistency in breeding the poultry population. Higher homozygosity also leads to high inbreeding, but the inbreeding rate is usually controlled to within reasonable levels. Currently, the commercial egg-producing companies implement this method to improve the productivity of their lines.

### 2.3.2. Cross breeding

Crossbreeding is widely used by poultry breeding companies to produce commercially viable breeds and strains. There are several reasons for producing crossbred birds. Crossbreeding is used for combining and averaging of breed effects. Two other observed for benefits of crossbreeding are heterosis effects (Fairfull, 1990). In order to overcome the adverse relationship between number of eggs and egg weight, commercial poultry breeding companies develop specialized lines for egg production and egg weights. They generally identify these lines as male and female lines. Crossing these differentially selected lines combines the high egg production ability of the female lines with the high egg weight of the male lines in the commercial chicken. Furthermore, heterosis effects from the crossbreeding also increases the performance of the crossbred chickens from those of their parent lines (Fairfull, 1990). Increase in the performance of the crossbred chicken over their parent lines is generally referred to as "hybrid vigour". For example, when males from the White Leghorn breed are crossed with females from the Australorp breed, the average egg production of the crossbred layer chicken increased 8% more than the average performance of the two purebred lines (Animal Husbandry Division, 2003).

Another notable benefit from crossbreeding is that the crossbred animal has more fitness than pure breeds. Therefore, crossbreeding is also used as a tool to improve the survival and productivity of indigenous breeds in developing countries (Kinghorn & van der Werf, 2013). Currently, crossbreeding is also used to develop high-performing new breeds and strains in the poultry industry. Most of the commercial poultry breeds or strains are three-way or four-way crossbreeding of differentially selected lines.

### 2.3.3. Hybrid vigour or heterosis

Heterosis is the term used when the performance of the progeny exceeds the average performance of the birds in their parent lines. Non-additive interactions between the loci are believed to be responsible for the heterosis effect. Therefore, heterosis is the outcome of the heterozygosity generated from the crossing of diversely selected breeds or lines. The average heterozygosity is expected to be equal in two-way, three-way, and four-way crosses.

Quantifying the level of heterosis in egg production traits is important for designing a layer breeding program. Heterosis in egg traits is highly variable and ranges from -11 to 29, as shown in Table 2-6. The highest heterosis is observed for hen house egg production, followed by egg yield and meat traits.

**Table 2-6 Average heterosis percentage for hen house egg production (HHP), hen day rate production (HDR), egg yield (EYLD), feed conversion (CONV), age at first egg (AFE), egg weight (EWT), Haugh units (HAU), percentage of egg blood spots (BSP), and body weight (BWT)**

| Detail | HHP | HDR | EYLD | CONV | AFE | EWT | HAU | BSP | BWT |
|---|---|---|---|---|---|---|---|---|---|
| **Two-way crosses** | | | | | | | | | |
| 1st egg production cycle | | | | | | | | | |
| Leghorn crosses | 12 | 8 | 16 | -5 | -4 | 2 | 1 | 0 | 3 |
| Rhode Island Red, crosses | 7 | | | | | 2 | | | 3 |
| Australorp x Leghorn crosses | 29 | 18 | 25 | -11 | -5 | 4 | | | 5 |
| Leghorn x RIR crosses | 14 | | | 9 | | 2 | | | 0 |
| Other egg-type crosses | 4 | 2 | 6 | -4 | -4 | 0 | | | 0 |
| Meat-type crosses | 19 | | | 11 | -4 | 3 | | | 4 |
| 2nd egg production cycle | | | | | | | | | |
| Leghorn crosses | 15 | 13 | 16 | -8 | | 2 | -1 | -2 | 4 |
| RIR crosses | 10 | | | | | 3 | | | 5 |
| **Three-way crosses** | | | | | | | | | |
| Leghorn crosses | 10 | 9 | 12 | 0 | -3 | 2 | 0 | -1 | 5 |
| RIR crosses | | | -9 | | | | | | -4 |
| **Four-way crosses** | | | | | | | | | |
| Leghorn crosses | 6 | 7 | 9 | 1 | -2 | 2 | 0 | -1 | 5 |
| $F_2$ crosses | | | | | | | | | |
| Leghorn crosses | 6 | 4 | 7 | 1 | 0 | 1 | 0 | -1 | 3 |
| Australorp x Leghorn crosses | -5 | -3 | 0 | | -2 | 3 | | | |
| $F_3$ crosses | | | | | | | | | |
| Australorp x Leghorn crosses | 3 | 2 | 3 | | -2 | 1 | | | |

Source: Fairfull (1990).

### 2.3.4. Synthetic populations

Crossbreeding is also used to establish new poultry breeds or strains. These new breeds and strains are called synthetic breeds and they tend to retain part of the heterosis generated by crossing differently selected breeds or strains. Some commercial layer companies are using synthetic birds to improve survival and productivity of their commercial layers flock.

### 2.3.5. Breeding objectives

Appropriate breeding objectives are required to improve the production potential of layer chickens. Breeding objectives are the guide to providing direction in breeding programs. A breeding objective is the combination of the economic and breeding value of traits a poultry breeding company would like to improve to increase profitability. Developing a breeding objective requires a breeding goal. Identification of the economically important traits and estimation of their economic values are important steps in defining a breeding goal. Hazel (1943) proposed the concept of a breeding objective by defining a breeding goal as a linear function of the breeding values of the economically important traits. Groen (2003) identified the economically important traits that could be considered in a breeding goal for layer poultry. These traits are summarized in Table 2-7.

**Table 2-7 Traits that could be considered for layer chicken breeding goals**

| Main trait group | Traits |
|---|---|
| Egg production level | Age first egg, hen-day egg production, persistency of production (rate of lay), pauses (broodiness), egg size/weight |
| Product quality | Outer: Egg deformation, shell thickness, colour, texture, porosity, and shape |
| | Inner : albumen quality, blood spots, taste |
| Production efficiency | Mature body weight, feed consumption (level and type of feed) |
| Reproductive performance | Female and male fertility, hatchability of eggs |
| Meat traits | Growth rate/body weight |
| | Body conformation (carcass, breast meat, wing, and leg yields) |
| Functional traits | Heat tolerance/adaptability |
| | Disease resistance, leg strength, survival, feeding behavior |
| | Maternal care, cannibalism, temperament (e.g. flightiness) |
| Others (e.g. type) | Plumage colour standard for the breed |

Source : Groen (2003).

Breeding goals may need to be changed according to the market situation and type of poultry breeding operation, for example, pure line, commercial poultry, backyard poultry breeding or dual purpose breeding. Furthermore, change in technologies may require renewed definitions of breeding goals. Change in farming systems from non-organic to organic in several countries may change their breeding goals. It is a challenge for the poultry breeders and poultry breeding companies to satisfy the market demands. However, due to technical difficulties, breeding objectives could also include simplified profit traits. For example, Francesch, Estany, Alfonso, and Lglesias (1997) used only egg number, egg weight, and egg shell colour to improve the productivity of different poultry breeds. Wolc et al. (2012) considered only egg defects, such as broken eggs, blood spots and double egg yolks, and egg quality traits such as albumen height, egg weight, yolk weight and puncture score in their breeding objective. In this study, age at first egg, weight at first egg, rate of lay, average egg weight and survivability are the five traits considered in the breeding objective of the DLD chicken.

A breeding objective for a laying hen can be written as:

$$H = \Sigma^{n}_{i=1} a_i BV_i$$

Where H is the aggregate genotype, BV is the breeding value for an economically important trait i, and $a_i$ is the economic value for one unit change in the breeding value of trait i while considering the other traits constant.

However, H is generally unknown to breeders; therefore, there is a need to construct an index with multiple sources of measurable phenotypic information which maximize the correlation between H and the Index. Hazel (1943) developed a selection index methodology to predict the genetic merit of a hen using information from multiple sources.

### 2.3.6. Selection index

A selection index is a method used by poultry breeders to improve several economically important traits. This uses the heritability, economic importance, and genetic and phenotypic correlation of the selected traits. Past selection experiments on livestock and poultry revealed that multiple index selection is more effective than individual trait or sequential selection (Falconer & MacKay, 1996). The selection index is the process which mixes all information of economically important characters (Groen, 2003). The advantage of a selection index is that it allows the prediction of an individual breeding value from multiple regressions. It also combines information from various sources, such as full sib, half sib, other relative and sex-limited traits (Falconer & MacKay, 1996).

Therefore, the index can be written as

$$I = \Sigma^{n}_{i=1} b_i X_i$$

Where I is the index value, X is the phenotypic information on trait i, and $b_i$ is the regression connecting phenotypic value to breeding objective.

There are several criteria that can be included in a selection index to improve the production potential of a poultry breed or strain. Those criteria can be the rate of laying, which is mostly measured in hen housed egg production (Stevens, 1991), total egg production, age at first egg, weight at first egg, egg number per hen per 120 days, and egg weight (Lwelamira, Kifaro, & Gwakisa, 2009). This implies that heritability, relative economic value, genetic and phenotypic correlation, and phenotypic standard variation of different characters need to be estimated to develop a selection index approach to realize the desired strain of DLD chicken.

### 2.3.7. Deriving economic weights

The development of a breeding objective requires the identification of all possible costs and returns on investment for a defined production system by using principles of bio-economic model profit function to evaluate. It needs the identification and evaluation of all costs associated with production, reproduction and growth of layer chickens, as well as the revenue generated by the sale of table eggs, culled chicken and by-products. Input costs can be variable or fixed costs and are generally influenced by the level of production. Day-old chicks, feed, management, and marketing are some of the variable input costs for a layer operation. Revenue comes from the sale of table eggs, culled chickens and by-products. Then the economic values can be calculated as the change in profitability of an enterprise after unit change in the trait of increase while holding all other traits constant. Partial budgeting or partial differentiation methods can be used for the estimation of economic values (Wolfova', Wolf, Pribyl, Zahra'dkova', & Kica, 2005). Management systems and marketing circumstances can influence the derivation of economic values and also the ranking of genotypes within a given production system. Therefore, it is recommended that separate economic values for different production systems be derived. Okeno, Magothe, Kahi, and Peters (2012) estimated economic values for two selection schemes, namely the pure line and crossbreeding selection schemes, and found that the pure line selection scheme was superior to crossbreeding scheme in Kenya.

### 2.3.8. Sensitivity analysis

Sensitivity analysis is a method of measuring the impact of changes in input and output values, such as animal breed cost, feed cost, management cost, and egg price. It can be used to assess how changes in inputs and outputs, and assumptions about such values, can affect the overall profitability. For example, a change in the price of an input would be regards as one variable, and the effect of this can be evaluated while keeping all other variables constant. This is useful tool in examining profitability under varying prices as well as forecasting future cost and profits. There are some examples of the use of sensitivity analysis in the literature. Pannell (1997) used sensitivity analysis to simulate the effect of price variations of 15, 20 and 25%. Hamra (2010) used it to predict the effect on profitability of a broiler enterprise if the day-old chick price rose by 36%, feed price by 15%, and the meat price decreased by 10%.

## 2.4. Genetics parameters

Genetic parameters help to assess the amount of genetic control in each of the economically important traits. They also help to decide on the type of selection programs that could be implemented to improve the overall production potential of a layer chicken. Genetic parameters generally include genetic variation, heritability, and genetic correlations between traits. Genetic parameters vary between populations, breeds and strains of layer bird (El-Labban, Iraqi, Hanafi, & Heba, 2011). It is important to use genetic parameters selection environment meet to optimize genetic gain through selection (Mulder & Bijma, 2005). Generally, the genetic parameters of laying hens are estimated using individual observations. Some studies have used group performance to estimate the genetic parameters (Nurgiartiningsih, Mielenz, Preisinger, Schmutz, & Schuler, 2002).

### 2.4.1. Heritability

Heritability ($h^2$) is the proportion of total variation between individuals in a given population due to additive genetic variation. This number can range from 0 (no genetic contribution) to 1 (all differences on a trait reflect genetic variation. It is one of the most important character predictors in the study of genetics. Breeders use heritability as a guide to predict the phenotype of an animal population (Falconer & MacKay, 1996). Breeders can use heritability to evaluate the estimated breeding values, EBV.

The heritability of birds is influenced by many factors, such as population, breed, strain, sex, age, and weight. For example, estimated heritability for age at first egg was slightly different for three indigenous chickens' breeds in Ethiopia. For Horro chickens, it was 0.06±0.15 (Dana, vander Waaij, & Arendonk, 2011) and for the Mandarah, and Matrouh, it was 0.01 (El-Labban et al., 2011). Heritability of egg production traits in a single battery cage system is different from that found in group cages (Anang, Mielenz, & Schuler, 2002). Nurgiartiningsih et al. (2002) studied genetic parameters for egg production and egg weight of laying hens housed in single and group cages. They reported that the single cage hens had higher heritability than group cage hens.

Age at first egg, body weight at first eggs egg, weight at first eggs, egg number, and egg weights have a major impact on egg production profitability. Estimated heritabilities for these five traits are summarized in Table 2-8. The heritability of age at first egg of layer chickens has been reported in several studies. The heritability of sexual maturity of the purebred chicken is different from the heritability of this trait in the crossbred chicken. Wei and van der Werf (1995) reported that the heritability for age at first egg of purebred and crossbred chicken was 0.91 and 0.23, respectively. Sang et al. (2006) reported the heritability of age at first age ranged from 0.12-0.32. This is supported by Maroof, Harpal, and Sharma (2005), Farzin, Vaez Torshizi, Kashan, and Gerami (2010), and Lambio (2010) who estimated that the heritability of age at sexual maturity was 0.16, 0.12, and 0.25, respectively. The variable of age at first egg heritability can be affected by difference in flock, hatch, and age. King and Henderson (1954) reported that the heritability of age at first egg in differed in each of the years 1948, 1949, and 1950 by 0.38, 0.25, and 0.14, respectively.

Few studies have examined the genetic influence on BWFE and EWFE. In 2006, Sang et al. (2006) reported the genetic parameters for economic traits of indigenous chickens in Korea. They reported that the heritability of BWFE ranged from 0.38 to 0.57. Maroof et al. (2005) also reported heritability of 0.34 ± 0.17 and 0.34 ± 0.18 for body weights at 2 weeks and 36 weeks, respectively. Estimated heritability for EWFE ranged from 0.06 to 0.74.

Total number of eggs laid by a hen is moderately heritable and ranged from 0.24 to 0.4 (Dana et al., 2011; Lerner & Cruden, 1948; Maroof et al., 2005; Wei & van der Werf, 2013; Wolc et al., 2012). However, a heritability of 0.91 was reported by Wei and van der Werf (1995) for crossbred birds. Moderate to high heritabilities have been reported for egg weight, with Besbes and Gibson (1998) reporting heritabilities of 0.52 to 0.71 for this trait. As observed with other traits, the estimated heritabilities for egg weight of crossbred chickens were higher than those of purebred chickens. Heritability of egg weight is influenced by hatch. For example, King and Henderson

(1954) reported heritability of egg weight in 1948, 1949, and 1950 to be 0.50, 0.50, and 0.80, respectively.

**Table 2-8 Published heritabilities for age at first egg (AFE), bodyweight at first egg (BWFE), egg weight at first egg (EWFE), egg number (EN), and egg weight (EW)**

| No. | References | AFE | BWFE | EWFE | EN | EW |
|---|---|---|---|---|---|---|
| 1 | Dana et al. (2011) | 0.06 | | | 0.24-0.35 | |
| 2 | El-Labban et al. (2011) | 0.01 | | | | |
| 3 | Wei and van der Werf (1995) | 0.23-0.91 | | | 0.40-0.74 | 0.27-0.63 |
| 4 | Sang et al. (2006) | 0.12-0.32 | 0.38-0.57 | 0.06-0.13 | | |
| 5 | Maroof et al. (2005) | 0.16 | 0.34 | | 0.29 | 0.08 |
| 6 | Farzin et al. (2010) | 0.12 | | | | |
| 7 | Lambio (2010) | 0.25 | | | | |
| 8 | King and Henderson (1954) | 0.14-0.38 | | | | 0.5-0.8 |
| 9 | Wolc et al. (2012) | | | 0.74 | 0.39 | |
| 10 | Lerner and Cruden (1948) | | | | 0.33 | |
| 11 | Besbes and Gibson (1998) | | | | | 0.52-0.71 |

### 2.4.2. Genetic correlations

A genetic correlation ($r_G$) quantifies the genetic association between different traits. Traits can be genetically correlated if the same genes are affecting both traits (pleiotropy) or if genes affecting both traits are linked. The correlation is useful in pursuing three breeding aims. Firstly, it is connected between genetic causes through gene action. Secondly, selection effect on gene is changed. Lastly, connection to the population is selected by natural factors (International Rice Research Institute, 2006). As observed with heritability, the genetic correlation varies between populations, breeds, strains, sex, age, and weight. Correlation can be both positive and negative.

Wolc et al. (2012) estimated genetic parameters of egg defects and egg quality in layer chickens. The purpose of this study was to estimate the heritability of livability of hens, and estimate genetic relationships between egg defects, egg production, and egg quality traits in layer birds. The correlation between egg number and egg weight was -0.27, and the correlation between egg number and body weight was -0.25. In contrast, the correlation between egg weight and body weight was 0.28. Additionally, using a multi-trait linear model analysis of total egg defects, they estimated that there was a positive genetic correlation with egg weight of 0.23 ±0.05, and body weight of 0.40 ±0.06. Zhang, Ning, Xu, Hou, and Yang (2005) reported that the genetic correlation between egg weight and albumen weight was high, ranging from 0.67 to 0.97.

In Spain, a study was conducted on three Catalan poultry breeds (Francesch et al., 1997); the Prat, the Penedesenca, and the Empordanesa, which are indigenous chickens in Spain. Genetic parameters for egg number, egg weight, and eggshell colour of the three breeds of layers birds were studied. The genetic and phenotypic correlation between egg number (EN until 39 weeks of age), egg weight (EW), and eggshell colour (SC) at 39 weeks of age in the three bird breeds are shown in Table 2-9. The genetic correlation between egg number and egg weight was negative with correlation coefficients of 0.22, -0.21, and -0.19 for the three breeds. Moreover, egg number and eggshell colour also had a negative correlation with correlation coefficients of -0.03, -0.06, and -0.29. In contrast, the genetic correlation between egg weight and egg shell colour was positive and ranged from 0.03 to 0.09.

El-Labban et al. (2011) studied the genetic correlation of egg production traits. They estimated the genetic correlation between egg economic traits and age at sexual maturity (ASM), body weight at sexual maturity (BWSM), weight of first egg (WFE), egg number in first 90 days (EN90D), and egg mass in first 90 days (EM90). They found that there was a positive correlation between ASM and BWSM, ASM and WFE, BWSM and WFE, EN90D and EM90D, and TEN and TEM with correlation coefficients of 0.84, 0.08, 0.61, 0.98, and 0.97, respectively. These results are similar to those of Jeyaruban and Gibson (1996) who also studied commercial egg production traits for the birds managed in environmentally controlled houses in temperate climate. They reported that the genetic correlation was positive for egg production traits such as rate of lay, age at first egg, egg weight, deformation, and body weight.

**Table 2-9 Genetic ($r_G$) and phenotypic ($r_P$) correlation between egg number (EN), egg weight (EW), and egg shell colour (SC) of Prat, Penedesenca, and Empordanesa chicken breeds of Spain**

| **Traits** | **Breeds** | | |
|---|---|---|---|
| | **Penedesenca** | **Prat** | **Empordanesa** |
| EN – EW | | | |
| $r_G$ | -0.22 | -0.21 | -0.19 |
| $r_P$ | -0.18 | -0.16 | -0.14 |
| EN – SC | | | |
| $r_G$ | -0.03 | -0.06 | -0.29 |
| $r_P$ | -0.02 | -0.09 | -0.07 |
| EW – SC | | | |
| $r_G$ | 0.00 | 0.09 | 0.30 |
| $r_P$ | 0.05 | 0.10 | 0.13 |

Source: Francesch et al. (1997).

## 2.5. Response to selection

The response to selection can be used as a measure for assessing the efficiency of a selection program. Response to selection is influenced by intensity of selection, level of genetic control for a trait, and the amount of variation in a trait. Population size, which determines the intensity of selection, also influences the amount of response that can be achieved in a selection study (van der Werf, 2013b). However, some factors or criteria cannot be achieved together. For instance, increasing the selection intensity decreases efficient population and leads to a decrease in response to selection (Muir, 1996). When selecting on individuals phenotypes response to single trait selection can be predicted as:

$$R = i.h^2.\sigma_P$$

Where R is the response to selection per generation, i is the selection intensity, $h^2$ is heritability, and $\sigma_P$ is the phenotypic standard deviation (Falconer & MacKay, 1996) .

The single trait selection response can also be estimated as:

$$R = i.h_1 \sigma_{A1}$$

Where R is direct response per generation for trait 1 when selection is practiced on trait 1, i is selection intensity, $h_1$ is the square root of heritability (i.e. the selection accuracy for selection on phenotype only) for trait 1, and $\sigma_{A1}$ is the genetic standard deviation.

Selection for one trait can have a correlated response with other traits. We can measure the correlated response for trait 2 when selection is practiced on trait 1 by using regression so that:

$$CR = i.h_1 r_g \sigma_{A2}$$

Where $r_g$ is the genetic correlation between traits 1 and 2.

Multi trait selection involves selection on a combination of the measured phenotypes for multiple traits. Nwagu et al. (2007) studied the response to selection of egg production in RIR chickens in a multiple trait selection study involving age at sexual maturity, egg number to 280 days, egg weight average, and body weight at 40 weeks of age They reported a genetic response of 0.42 eggs per generation in the male lines and 3.14 eggs per generation in the female lines. The breeder can use annual response to selection to predict the genetic progress for the next generation. Alshami (2014) used annual response to selection to predict the genetic progress of the following 10 years in Leghorn, Fayoumi, crossbred, and hybrid chickens based on egg number (EN), body weight at sexual maturity (BWSM), age at sexual maturity (ASM), survivability (SUR) and disease resistance (DR). In summary application of multi-trait selection index approach, is expected to improve the production potential of the RIR, WPR and their crosses in Thailand.

# Chapter 3. Genetic Parameters for Egg Production Traits in Purebred and Hybrid Chicken in a Tropical Environment

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## 3.1. Abstract

1. Genetic parameters were estimated for 5 economically important egg production traits using records collected over 9 years on chicken reared under tropical conditions in Thailand. 2. The data was from two purebred lines and two hybrid lines of layer parent stocks. 3. The two purebred lines were Rhode Island Red (RIR) and White Plymouth Rock (WPR) and the hybrid lines were formed by crossing a commercial brown egg laying strain to Rhode Island Red (RC) and White Plymouth Rock (WC), respectively. 4. Five egg production traits were analyzed, including age at first egg (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), number of eggs from first seventeen weeks of lay (EN) and average egg weight over $17^{th}$ weeks of lay (EW). 5. Fixed effects of year and hatch within year were significant ($P \leq 0.05$) for all five traits and were included in the model. 6. Maternal genetic and permanent environmental effects of the dam were not significant, except for EN and EW in RIR and BWT and EW in WPR. 7. Estimated heritability of AFE, BWT, EWFE, EN and EW were 0.45, 0.50, 0.29, 0.19 and 0.43 in RIR, 0.44, 0.38, 0.33, 0.20 and 0.38 in WPR, 0.37, 0.41, 0.38, 0.18 and 0.36 in RC and 0.46, 0.53, 0.36, 0.38 and 0.45 in WC lines, respectively. 8. The EN was negatively correlated with other traits, except for BWT in RC and AFE and BWT in WC. 9. We conclude that selection for increased EN will reduce other egg production traits in purebred and hybrid chicken. 10. Therefore, EN needs to be combined with other egg production traits in a multi-trait selection index to improve all traits optimally according to a defined breeding objective.

## 3.2. Introduction

The poultry industry is an important livestock sector in Thailand because it supports household income and employment generation, as well as to foreign exchange earnings (Tongsiri & Jeyaruban, 2014). The layer industry plays a significant role because it provides eggs for local consumption. Prior to 1924, eggs for local consumption were mainly obtained from the backyard poultry production system. Since 1924, layer chickens were imported to Thailand from the U.S.A. and Australia to improve the productivity of the commercial egg industry (Sopha et al., 2012). This importation is still continuing and currently about 259,000 day old layer chicks were imported from the Netherlands, France and the U.S.A. (Information Technology Center, 2008).

In order to be self- sufficient for egg production, a layer chicken breeding program was initiated by the Thai Department of Livestock Development in 2004. Two pure lines were established from the imported but locally adapted Rhode Island Red (RIR) and White Plymouth Rock (WPR) populations. RIR and WPR lines were selected for longer than 40 years under Thai condition. Furthermore, two hybrid lines were established by crossing the RIR (RC) and WPR (WC) separately to a brown egg laying commercial strain. Hybrid chicken produced by crossing the two pure lines and the two hybrid lines were issued to backyard and commercial poultry production systems, respectively. A recent evaluation of the performance of these hybrid chicken revealed that both of the hybrid layer birds had a survival rate of more than 85% up to a year of lay and produced 260 eggs per year (71% rate of lay) under rural poultry management conditions in Thailand (Sopha et al., 2012). However, their productivity needs to be improved to make them more competitive with imported layer strains in Thailand, which lay 330 eggs per year and have a survival rate of 93% under intensive farm management (Bureau of Feed Maketing and Animal Breed, n.d.).

Implementation of selection schemes to maximize genetic improvement of specific traits requires accurate estimates of genetic and phenotypic (co)variance components (Falconer & MacKay, 1996). These estimated (co)variances can be used to estimate heritability and correlations between traits, and to predict breeding values (Henderson, 1986). There are many published studies reporting estimates of genetic parameters for egg production traits under temperate conditions (Dana et al., 2011; Lerner & Cruden, 1948; Wei & van der Werf, 1995). The genetic parameters estimated for poultry populations managed under environmentally controlled housing in temperate climates may not be applicable to poultry managed under tropical conditions with high humidity and high temperatures. It is important to use genetic parameters specific to the selection environment to optimize genetic gain through selection (Mulder & Bijma, 2005). However, published reports on estimated genetic parameters for egg production in tropical or subtropical environments are limited. The objective of this study was to estimate genetic parameters for five economically important egg production traits measured in two purebred and two hybrid lines, under tropical climatic conditions in Thailand.

## 3.3. Materials and Methods

### 3.3.1. Layer improvement program

A layer improvement program was initiated in 2004 at the Kabinburi Livestock Research and Breeding Center, Department of Livestock Development in Thailand. The Livestock Research Centre is situated between 14.0478° North latitude and 101.3725° East longitude and it is located in the Eastern region of Thailand. It has an average annual rainfall of approximately 1,380 mm and the average daily maximum temperature varies from 23 to 33°C. The purebred RIR and WPR lines were established from populations that were imported in 1992 but locally managed ever since. The WPR line was maintained for feather sexing. The WPR line has the required silver gene to identify to males and females chicks. Two hybrid lines, known as RC and WC, were established in 2005 by crossing RIR and WPR lines with a brown egg laying commercial strain. The advantage of crossing two purebred lines with a brown commercial line was to improve egg number and egg weight in the crossbred chicken. Each year, two hundred hens and forty cocks were maintained in each line. Each sire was mated to 5 dams and each dam produced about 10 day old chicks for breeding purposes. Replacement day old chicks were kept in deep-litter housing from day of hatch until 16 weeks of age. Before the onsets of lay pullets were moved to individual battery cages housed in an open housing system and their individual performances were recorded. Within line selection was implemented in 2004. Hens were selected after a test period of 17 weeks based on their own egg production performance and the cocks were selected in a two stage process; first as day old chicks males based on their mothers performance and second as breeding cocks based on the layer performance of their sisters. Replacement males and females were selected using an index comprising estimated breeding values for age at first egg (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), total number of eggs up to 17 weeks of lay (EN) and average egg weight at the $17^{th}$ week of lay (EW).

Chicks were reared on deep litter house with 7.5 chicks per one square meter until moved to battery cages and the laying hens were on single battery cage with 70 square inch per bird. Light schedule of layer flock was 24 hours during first 3 weeks of age after that artificial light was reduced and allowed only natural daylight until 19 weeks of age. Then, the light schedule was steadily increased with 1 hour per week until reached to 16 hours per day. It was 16 hours of light per day during laying period by providing 12 hours of natural daylight and 4 hours of artificial light, and continues until end of period. Chicken were fed *ad libitum* during starterer period (hatch to 6 weeks of age), fed *ad libitum* daily and skip in night time during grower period (7 to 16 weeks), and fed adequately in laying period (17 to 72 weeks of age). Feed was provided with a diet containing ≥190g crude protein (CP) per kg and 2800 kcal/kg metabolisable energy (ME) during the starter period, ≥150g CP per kg and 2850 kcal/kg ME during grower period and ≥170g CP per kg and 2900 kcal/kg ME during the laying period. The conventional feed ingredients used in layer poultry diet were corn or broken rice, rice bran, leucaena leaf powder, soybean meal, fish meal, shell, some mineral and some feed additional. Clean water was provided for *ad libitum.* All birds were vaccinated for New Castle disease (ND), Infectious Bronchitis disease (IB), Fowl Pox disease, Fowl Cholera and Marek's disease as recommended by the Department of Livestock Development of Thailand.

### 3.3.2. Traits studied

The AFE is the age of the hen when her first egg is laid and it is the starting day for recording egg performance data for each hen. Hens were reared on a floor before being moved to individual battery cages at 16 weeks of age and hens laid their first egg in individual battery cages. The BWT is the weight (kilograms) of the hen when she laid her first egg in the individual battery cage. The EWFE is the weight (grams) of the first egg of an individual hen. The EN is the total number of eggs per hen from the start of lay until the end of the $17^{th}$ week after the start of lay. The EW is the average weight of eggs (grams) at week $17^{th}$ of lay.

### 3.3.3. Data preparation

Phenotypic records within four standard deviations from the population mean were kept for this analysis. Year of hatch and line could be derived from the bird ID. There were 9 years of hatch (2004 to 2012) with 2 to 3 hatches within each year for the 4 lines (RIR, WPR, RC and WC). Sire and dam ID were known for each bird and a 9 generation pedigree was available for all birds with records. Data was analyzed separately for each line. Records of birds with missing dams' identification were removed to estimate maternal and permanent environmental effects of dam. About 0.5% to 6% of the records without dam's identification were removed for the five traits. The total number of hens with production records was 11,195 hens and the total number of individuals in the pedigree was 33,144. The 11,195 birds descended from 652 sires and 3,892 dams. The 3,892 dams had also records for the five traits.

### 3.3.4. Statistical analyses

The descriptive statistics of the five traits were carried out using PROC GLM in the SAS program (SAS, 2010). The normality of the distribution for each trait was examined using PROC UNIVARIATE in SAS. Important fixed effects were fitted along with random sire effect and were tested for significance for each trait using the PROC MIXED procedure in SAS. Fixed effects that were significant were included in the model used for estimating genetic parameters.

Estimates of (co) variance components and solutions for random effects were obtained by REML using an AI algorithm in the WOMBAT program (Meyer, 2007). The influence of maternal genetic and permanent environmental effects of the dam was explored by fitting four different models for each trait. The four models were,

Model A: $\mathbf{Y = Xb + Z_1a + e}$

Model B: $\mathbf{Y = Xb + Z_1a + Z_2m + e}$

Model C: $\mathbf{Y = Xb + Z_1a + Z_3pe + e}$

Model D: $\mathbf{Y = Xb + Z_1a + Z_2m + Z_3pe + e}$

Where:

Y = the vector of observation of one of the five egg production traits;

b = the vector of fixed effects (hatch and year effects);

a, m and pe are the vectors of direct additive genetic effect, maternal genetic effect and permanent environmental effect of dam, respectively;

e = the vector of random residual effect;

$X$, $Z_1$, $Z_2$ and $Z_3$ are incidence matrices relating records to the fixed, direct additive genetic, maternal genetic and permanent environmental effects, respectively.

The (co)variance structures for the random effects included in the four models were denoted as $var(a) = A\sigma^2_a$, $var(m) = A\sigma^2_m$, $var(pe) = I_d\sigma^2_{pe}$, where A is the numerator relationship matrix and $I_d$ is an identity matrix of order d, where d is the number of dam with progeny records.

The covariance between all random effects was assumed to be zero.

The likelihood ratio test was used to assess the significance of fitting various random effects in the models. A chi square distribution with one degree of freedom was used as the critical test statistic. The inclusion of the effect was considered significant when twice the difference in the Log likelihood of nested models differing by one random factor was greater than the critical value 3.84 ($\alpha = 0.05$). Significant random effects were included in the final model. Estimated genetic parameters, heritabilities and genetic correlations were based on the best model identified in the previous step. Heritabilities for all traits in each breed were estimated using univariate analysis. Bivariate analysis between all combinations of egg traits were used to estimate genetic correlations.

## 3.4. Results

### 3.4.1. Data statistics

As indicated by their earlier age at first egg, hens from the hybrid lines reached sexual maturity about 2 weeks earlier than their purebred counterparts (Table 3-1). RIR reached sexual maturity slightly earlier than WPR hens. Among the hybrid lines, RC reached sexual maturity slightly earlier than WC.

The RIR birds reached sexual maturity when their body weight was 1.9 kg, which was about 200 g heavier than the body weight of WPR hens at sexual maturity. In the hybrid lines, the RC line was also 200g heavier than the WC line when they reached their sexual maturity. On average, the hybrid hens were 100g heavier than the respective purebreds at sexual maturity.

RIR hens laid heavier eggs (42.8g) at the onset of lay than WPR hens (37.3g). The variation in egg weight at first egg was very similar for both lines. Similar to the two pure lines, the RC line laid heavier eggs (4g on average) than the WC line. On average, the hybrid hens laid heavier first eggs than their purebred counter parts. Generally within their first $17^{th}$ weeks of lay, the RIR hens laid more eggs than WPR hens. The RC hens also laid slightly more eggs than WC hens.

The average egg weight in the $17^{th}$ week of lay was 53g for RIR hens, which was 3g heavier than those of WPR hens at a similar stage. The RIR hybrids also laid heavier eggs than WPR hybrids. Average weight of eggs laid in the $17^{th}$ weeks of lay by hybrid hens was heavier than those of the pure lines. Hybrid hens laid heavier eggs at the start of their lay and were expected to also lay heavier eggs relative to the purebred hens.

**Table 3-1 Descriptive statistics for age at first egg (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), egg number (EN), and egg weight at 17th week of lay of RIR, WPR, RC and WC lines**

| Traits | No. of records | Mean | Std. | No. of records | Mean | Std. |
|---|---|---|---|---|---|---|
| **Pure lines** | | **RIR** | | | **WPR** | |
| AFE, days | 3,940 | 175.50 | 12.15 | 3,426 | 177.62 | 14.02 |
| BWT, kg | 4,249 | 1.90 | 0.20 | 3,438 | 1.70 | 0.20 |
| EWFE, g | 3,940 | 42.78 | 4.73 | 3,259 | 37.30 | 4.17 |
| EN, eggs | 3,968 | 98.94 | 11.39 | 3,344 | 91.43 | 16.28 |
| EW, g | 3,855 | 52.49 | 4.19 | 3,102 | 49.63 | 4.08 |
| **Hybrid lines** | | **RC** | | | **WC** | |
| AFE, days | 2,134 | 163.35 | 10.70 | 1,374 | 162.95 | 15.50 |
| BWT, kg | 2,095 | 1.80 | 0.20 | 1,355 | 1.60 | 0.20 |
| EWFE, g | 2,132 | 43.66 | 4.96 | 1,374 | 39.72 | 4.43 |
| EN, eggs | 1,836 | 100.58 | 12.50 | 996 | 104.67 | 8.22 |
| EW, g | 1,759 | 53.08 | 4.75 | 1,090 | 51.57 | 4.31 |

RIR = Rhode Island Red breed, WPR = White Plymouth Rock breed, RC = hybrid derived from RIR x a brown strain crossing, WC = hybrid derived from WPR x a brown strain crossing

### 3.4.2.Fixed effects

Fixed effects and their significance levels for each of the five traits in the four lines are given in Table 3-2. Year and hatch within year were highly significant (P<0.001) for all traits in all four lines, except for hatch within year for EW trait in the RC line (Table 3-2).

**Table 3-2 Significance of fixed effects for age at first egg (AFE) body weight at first egg (BWT), egg weight at first egg (EWFE) total egg number from week 1 to week 17 (EN) and egg weight at 17$^{th}$ week of lay (EW)**

| Line | Fixed Effect | AFE | BWT | EWFE | EN | EW |
|---|---|---|---|---|---|---|
| RIR | Hatch (year) | *** | *** | *** | *** | *** |
| | Year | *** | *** | *** | *** | *** |
| WPR | Hatch (year) | *** | *** | *** | *** | *** |
| | Year | *** | *** | *** | *** | *** |
| RC | Hatch (year) | *** | *** | ** | ** | ns |
| | Year | *** | *** | *** | *** | *** |
| WC | Hatch (year) | *** | *** | * | * | *** |
| | Year | *** | *** | ** | *** | *** |

ns = not significant, * = P<0.05, ** P = <0.01, *** = P < 0.001

### 3.4.3. Variance components

Models identified from the likelihood ratio test for the estimation of genetic parameters for the five traits in all four lines are given in Table 3-3 and the estimated variance components from the different models are given in supplementary Table 3-5, Table 3-6, Table 3-7 and Table 3-8 for

RIR, WPR, RC and WC lines, respectively. Fitting maternal effects for AFE, in models B and C, increased the maximum log likelihood over the model with direct additive effect (model A) in all four lines. However, the likelihood improvement was not significant ($p > 0.05$). Therefore, the model with direct additive effect (model A) was adequate to estimate genetic parameters for AFE in all four lines.

For BWT, fitting a maternal genetic effect did not significantly ($P \leq 0.05$) improve the log likelihood in all four lines except for WPR. Similarly, for EWFE fitting maternal effects did not significantly improve the log likelihood.

For EN, inclusion of maternal genetic (model B) or maternal permanent environment effect (model C) significantly increased the log likelihood compared to model A for RIR hens but not for WPR and the two hybrid lines (Table 3-3).

For EW, maternal effect was generally not significant, except for WPR and permanent environment effect (Model C) was not significant for WPR and WC lines.

**Table 3-3 Models identified from the log likelihood ratio test to use in the univariate analysis to estimate genetic parameters for AFE, BWT, EWFE, EN and EW of RIR, WPR, RC and WC lines**

| Line | Trait[1] | Model[2] | | Statistics | Significance[4] |
|---|---|---|---|---|---|
| | | Identified (n) | Compared (m) | $-2[(Ln^3-Lm)]$ | $(\chi^2_1)$ |
| RIR | AFE | A | | | |
| | BWT | A | | | |
| | EWFE | A | | | |
| | EN | D | B | 3.98 | * |
| | EW | C | A | 4.10 | * |
| WPR | AFE | A | | | |
| | BWT | B | A | 8.08 | ** |
| | EWFE | A | | | |
| | EN | A | | | |
| | EW | B | A | 6.72 | * |
| RC | AFE | A | | | |
| | BWT | A | | | |
| | EWFE | A | | | |
| | EN | A | | | |
| | EW | C | A | 4.60 | * |

| | | |
|---|---|---|
| WC | AFE | A |
| | BWT | A |
| | EWFE | A |
| | EN | A |
| | EW | A |

[1] AFE = age at first egg, BWT = body weight at first egg, EWFE = egg weight at first egg, EN = total egg number from 1st week to week 17th of lay, EW = average egg weight at week 17th of lay

[2] Model A = direct genetic effect + year + hatch(year), Model B = Model A + maternal genetic effect, Model C = Model A + permanent environmental effect of dam, Model D = Model A+ maternal genetic effect + permanent environmental effect of dam

$\sigma^2_d$ = direct genetic variance, $\sigma^2_m$ = maternal genetic variance, $\sigma^2_p$ = permanent environmental variance, $h^2_d$ = direct heritability, $h^2_m$ = direct-maternal heritability, [3] Ln = the highest log likelihood obtain by fitting higher order model n.

[4] * = $P \leq 0.05$ and ** = $P \leq 0.001$

### 3.4.4. Genetic parameters

#### *3.4.4.1. Heritability ($h^2$)*

Estimated heritabilities and genetic correlations for five egg production traits in four lines are given in Table 3-4. Heritabilities and genetic correlations were estimated using models identified as the best models for each trait from the log likelihood test. The heritabilities were moderate and similar between all four lines for all five traits. Estimated heritabilities ranged from 0.37 (RC) to 0.46 (WC) for AFE, 0.38 (WPR) to 0.53 (WC) for BWT, 0.29 (RIR) to 0.38 (RC) for EWFE, 0.18 (RC) to 0.38 (WC) for EN and 0.36 (RC) to 0.45 (WC) for EW. The heritabilities of AFE, BWT, EN and EW were slightly lower in RC compared with the other lines. Purebred lines had slightly higher heritability than hybrid lines that ranking.

**Table 3-4 Heritability (on the diagonal), genetic correlations (above diagonal) and phenotypic correlation (below diagonal) for age at first age (AFE), body weight at first egg (BWT), egg weight at first egg (EWFE), total egg number (EN) and egg weight at $17^{th}$ week of lay (EW) of RIR, WPR, RC and WC lines and the approximate standard error in the parenthesis**

| Line | Traits | AFE | BWT | EWFE | EN | EW |
|---|---|---|---|---|---|---|
| RIR | AFE | **0.45 (0.04)** | 0.33 (0.07) | 0.38 (0.08) | -0.17(0.09) | 0.16 (0.07) |
| | BWT | 0.23 (0.02) | **0.50 (0.04)** | 0.40 (0.07) | -0.03 (0.09) | 0.47 (0.06) |
| | EWFE | 0.33 (0.02) | 0.23 (0.02) | **0.29 (0.04)** | -0.22 (0.10) | 0.71 (0.06) |
| | EN | -0.14(0.02) | -0.04(0.02) | -0.10 (0.02) | **0.19 (0.04)** | -0.37(0.09) |
| | EW | 0.14 (0.02) | 0.23 (0.02) | 0.37 (0.02) | -0.10 (0.02) | **0.43 (0.04)** |
| WPR | AFE | **0.44 (0.04)** | 0.18 (0.08) | 0.56 (0.07) | -0.33 (0.10) | 0.21 (0.08) |
| | BWT | 0.20 (0.02) | **0.38 (0.04)** | 0.35 (0.08) | -0.05 (0.11) | 0.54 (0.07) |
| | EWFE | 0.38 (0.02) | 0.26 (0.02) | **0.33 (0.04)** | -0.24 (0.11) | 0.69 (0.06) |
| | EN | -0.13 (0.02) | -0.06 (0.02) | -0.07 (0.02) | **0.20 (0.04)** | -0.08 (0.11) |
| | EW | 0.14 (0.02) | 0.26 (0.02) | 0.35 (0.02) | -0.02 (0.02) | **0.38 (0.04)** |
| RC | AFE | **0.37 (0.05)** | 0.21 (0.10) | 0.53 (0.08) | -0.20 (0.15) | 0.36 (0.10) |
| | BWT | 0.16 (0.03) | **0.41 (0.05)** | 0.31 (0.10) | 0.04 (0.15) | 0.62 (0.08) |
| | EWFE | 0.39 (0.02) | 0.20 (0.03) | **0.38 (0.05)** | -0.42 (0.13) | 0.85 (0.05) |
| | EN | -0.14 (0.03) | 0.06 (0.03) | -0.20 (0.03) | **0.18 (0.05)** | -0.63 (0.11) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | EW | 0.20 (0.03) | 0.26 (0.03) | 0.43 (0.02) | -0.22 (0.03) | **0.36 (0.05)** |
| | | | | | | |
| WC | AFE | **0.46 (0.06)** | 0.10 (0.11) | 0.36 (0.11) | 0.06 (0.16) | 0.16 (0.12) |
| | BWT | 0.14 (0.03) | **0.53 (0.06)** | 0.13 (0.12) | 0.19 (0.15) | 0.42 (0.10) |
| | EWFE | 0.36 (0.03) | 0.18 (0.03) | **0.36 (0.06)** | -0.14 (0.17) | 0.63 (0.09) |
| | EN | -0.08 (0.03) | 0.09 (0.03) | -0.08 (0.03) | **0.38 (0.06)** | -0.37 (0.15) |
| | EW | 0.11 (0.04) | 0.25 (0.04) | 0.44 (0.03) | -0.13 (0.04) | **0.45 (0.06)** |

#### *3.4.4.2. Genetic correlations ($r_G$)*

Genetic correlations between the five traits in the four lines are given in Table 3-4. In all four lines AFE had a low to moderate positive correlation with BWT, EWFE and EW and was negatively correlated with EN, except in the WC line. None of these estimates differed significantly from zero ($P \geq 0.05$). BWT had a moderate to high positive correlation with EWFE and EW in all lines, except in the WC line where BWT had a low positive genetic correlation with EWFE. EWFE was highly correlated with EW in all four lines and the correlation ranged from 0.63 to 0.85.

#### *3.4.4.3. Phenotypic correlation ($r_P$)*

The phenotypic correlations for all four lines are shown in Table 3-4. Overall, the phenotypic correlations between all five egg production traits are positive; except for EN with other traits.

## 3.5. Discussion

Genetic parameters for economically important egg production traits in pure line and hybrid line chicken were estimated. Such parameters are needed to implement genetic improvement programs to increase productivity of layer chicken in Thailand. Phenotypic differences were observed between the two purebred lines and between the two hybrid lines that were formed from crossing these purebreds with a brown egg laying commercial chicken population. The RIR hens reached sexual maturity earlier and laid more eggs with higher egg weight than the WPR hens. Although the RIR breed was superior to the WPR breed for all five traits, crossing with WPR is required for feather sexing of day old chicks. Overall, the phenotypic differences between the RIR and WPR hens for the five egg production traits suggest that the RIR breed could be used as the female line with higher emphasis on egg weight (EW) and egg number (EN), and WPR breed could serve as a male line with more emphasis on less body weight at first egg than RIR line. Monira, Salahuddin, and Miah (2003) also reported that RIR hens laid more eggs with heavier egg weight than WPR hens, and egg production of hybrid hens was superior to purebred hens. Hens from both hybrid lines attained sexual maturity 10 days earlier than purebred hens. The body weights of hybrid hens were 100 g lighter than purebred hens at sexual maturity. Egg weight at the onset of lay and egg weight at 17 weeks of lay of hybrid hens were heavier than those of purebred hens. Total number of eggs laid by hybrid hens during their first 17 weeks of lay was slightly higher than purebred hens. The superior productivity of the hybrid hens over the purebred hens suggests that the two hybrid lines could further improve egg production traits under commercial poultry production.

Direct additive genetic effects were the main source of genetic variation in all egg production traits in pure and hybrid hens. Except for EN in RIR and BWT and EWT in WPR, maternal genetic and maternal permanent environmental effects were not significant in any of the four lines. Prado-Gonzalez, Ramirez-Avila, and Segura-Correa (2003) also reported no significant influence of maternal effects for layer chicken, and suggested that this was because they were raised separately from their dam. However, the significant maternal effect observed for EN of RIR and BWT and EWT of WPR hens was in agreement with Kamali, Ghorbani, Moradi Sharbabak, and Zamiri (2007). The maternal influence may be through egg size, which has a higher genetic association with BWT and EW.

All five egg production traits were moderately heritable in all four lines. Estimated heritabilities for the purebred hens were similar to those of hybrid hens. Wei and van der Werf (1995) found higher heritabilities for egg weight of purebred hens than those of hybrid F1 hens. This is because the crossbred lines were managed in commercial condition which may be less favorable than the pure line management. The genetic variance in the first crosses between purebred lines is expected to be lower than in the hybrid lines which benefit from increased segregation variance after crossing. Moderate heritabilities estimated in this study for the five egg production traits for purebred and hybrid hens agreed with the values reported in previous studies (Francesch et al., 1997; Niknafs, Nejati-Javaremi, Mehrabani-Yeganeh, & Fatemi, 2012; Nurgiartiningsih et al., 2002; Sang et al., 2006; Savegnago et al., 2011; Siegel, 1961; Wei & van der Werf, 1995). Most of these studies reported heritabilities for total egg production for a period of one year or more. Estimated heritabilities in this study were reported for 17 weeks of lay and were about 0.20 for most of the lines. This is closer to the value 0.14 reported by Fairfull and Gowe (1990) for rate of lay measured during first 20 weeks of production. Therefore, this study suggests that the heritabilities for egg production traits of hens managed under tropical climate are similar to those under temperate climatic conditions.

Negative genetic association between EN and other traits were clearly evident, with the exception for WC. Although a positive genetic correlation was observed for EN and AFE in WC, the observed genetic correlation was not significantly different from zero (P > 0.05). The negative correlations between EN and other traits suggest that selection for EN will reduce AFE, body weight at sexual maturity and egg weight at sexual maturity and at 17$^{th}$ week of lay. Stronger negative correlations between EN and other traits were observed by (Savegnago et al., 2011; Wolc et al., 2012) and they ranged from -0.85 to -0.27. Moderately negative genetic correlations of -0.23 and -0.31 between rate of lay measured from the first 20 weeks of production and AFE and EW, respectively, were reported by Fairfull and Gowe (1990) . A negative genetic correlation between AFE and EN suggests that hens that reach sexual maturity at an early age are genetically inclined to lay more eggs than hens that reach sexual maturity later. The negative genetic association between AFE and EN was not evident in the RC line. Aghazadeh Bokat et al. (2014) agreed that the sexual maturity was correlated negatively to egg production traits.

We found AFE was positively correlated with BWT, EWFE and EW in all four lines, with the estimated genetic correlation between AFE and BWT ranging from 0.10 to 0.33. Positive genetic correlations between AFE and BWT were reported by some researchers (El-Labban et al., 2011; Lwelamira et al., 2009; Sang et al., 2006) and ranged from 0.01 to 0.84. Positive correlations between AFE and EWFE were reported to range from 0.08 to 0.66 (El-Labban et al., 2011; Niknafs et al., 2012; Sang et al., 2006). This suggests that selection for AFE will reduce EWFE and EW in all four lines. Moreover, Koutoulis, Perry, and Lewis (1997) reported that hens with longer AFE had heavier egg weight than hens with shorter AFE.

The correlations between BWT, EWFE and EW estimated in this study ranged from 0.13 to 0.40 for BWT and EWFE and 0.42 to 0.62 for BWT and EW. El-Labban et al. (2011) reported a genetic correlation of 0.61 between BWT and EWFE for the local strains of chicken in Egypt. Lwelamira et al. (2009) and Wolc et al. (2012) reported a correlation of 0.28 and 0.34, respectively, between BWT and EW. This indicates that hens with heavier BWT lay fewer eggs than hens with lighter body weight at sexual maturity. However, hens with heavier BWT lay heavier egg than hens with lighter BWT.

Highly positive correlations between EWFE and EW were observed in this study for both purebred and hybrid lines. The similar high correlations ranging from 0.60 to 0.77 were found by Niknafs et al. (2012) and Sang et al. (2006) for native chicken. The high positive genetic correlation between EWFE and EW suggests that the hens that lay heavier eggs at sexual maturity continued to lay heavier eggs in the latter part of their production. Estimated genetic correlations among the five traits in all four lines, suggest that implementation of a selection strategy to reduce age at sexual maturity (AFE) is expected to reduce body weight at maturity and to increase the number of eggs during the laying period. Any reduction in weight at maturity will reduce management cost by reducing feed cost for maintenance. However, positive correlations between AFE and EWFE and EW indicated that reduction in AFE could leads to reduction in EWFE and EW. This means that the number of eggs below standard weight may increase, which would lead to lower income from the sale of eggs. Furthermore, reduction in egg weight leads to reduction in the number of eggs selected for hatching.

Rate of lay (84%) and average egg weight (53g) of the hybrid chicken were below the production level (rate of lay of 90%) of the imported commercial layer strains in Thailand (Bureau of Feed maketing and animal breed, n.d.). Moreover, the consumers in Thailand prefer egg weights 55g or more (Bureau of Feed Maketing and Animal Plan, 2015). Therefore, the production potential of the hybrid chicken need to be improved. Moderate heritabilities for all traits in all four lines suggest that further improvement of these traits could be achieved through selection. A multitrait selection strategy is required to improve all five traits at desirable levels. Furthermore, breeding objective with economic values derived for improvements for each of this trait in required to determine 'desirable levels'.

Backyard poultry production system accounted for 6% of all egg produced in Thailand (Information Technology Center, 2012). However, it is a low input system and does not require production level of a commercial system. Therefore, the crossbred layer chicks from the pure lines are identified for this system. However, keeping records may be difficult under this system. Therefore, multi-trait selection strategies will be implemented for the two pure lines to improve the production performance of their crosses in the backyard production system. Regular monitoring of the performance of the crossbred layer under the backyard system is required to optimize the productivity.

In conclusion, phenotypic differences exist for the five egg production traits among the purebred and crossbred hens. This could be used in the development of specialized lines to improve egg productivity in backyard and commercial production systems in Thailand. Heritabilities in purebreds were slightly higher than in the hybrid lines for all five traits in the purebred and crossbred hens and there were low to moderate. With the exception of BWT and EW traits of WPR, influence of maternal and permanent environmental effect on dam was minimal on all egg production traits studied. Heritabilities and correlations estimated for the five traits in all four lines under tropical climate in Thailand were similar to the estimate obtained for hens managed under environmentally controlled house. Estimated genetic parameters will be used in genetic improvement program to increase layer chicken productivity in Thailand.

## 3.6. Acknowledgements

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## 3.7. Supplementary tables

**Table 3-5 Estimated variance components of direct additive genetic, maternal genetic and maternal permanent environmental effects for egg production traits in the RIR line**

| Traits[1] | Model[2] | Variance components | | | Genetic parameters | | |
|---|---|---|---|---|---|---|---|
| | | $\sigma^2_d$ | $\sigma^2_m$ | $\sigma^2_{pe}$ | $h^2_d$ | $h^2_m$ | $h^2_{pe}$ |
| AFE | A | 54.80 | | | 0.45 | | |
| | B | 51.26 | 2.34 | | 0.42 | 0.02 | |
| | C | 51.73 | | 2.02 | 0.43 | | 0.02 |
| | D | 50.80 | 1.68 | 0.94 | 0.42 | 0.01 | 0.01 |
| BWT | A | 23964.8 | | | 0.50 | | |
| | B | 22527.1 | 894.17 | | 0.47 | 0.02 | |
| | C | 22807.5 | | 894.70 | 0.48 | | 0.02 |
| | D | 22479.1 | 347.35 | 700.47 | 0.47 | 0.01 | 0.02 |
| EWFE | A | 6.50 | | | 0.29 | | |
| | B | 6.50 | 0.00 | | 0.29 | 0.00 | |
| | C | 6.16 | | 0.25 | 0.28 | | 0.01 |
| | D | 6.17 | 0.00 | 0.25 | 0.28 | 0.00 | 0.01 |
| EN | A | 28.91 | | | 0.24 | | |
| | B | 24.99 | 3.29 | | 0.21 | 0.03 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | 22.32 | | 4.87 | 0.19 | | 0.04 |
| | D | 22.19 | 0.78 | 4.28 | 0.19 | 0.01 | 0.04 |
| EW | A | 7.90 | | | 0.46 | | |
| | B | 7.36 | 0.36 | | 0.43 | 0.02 | |
| | C | 7.34 | | 0.43 | 0.43 | | 0.02 |
| | D | 7.31 | 0.00 | 0.41 | 0.43 | 0.00 | 0.02 |

[1] AFE = age at first egg, BWT = body weight at first egg, EWFE = egg weight at first egg, EN = total egg number from 1st week to week 17th of lay, EW = average egg weight at week 17th of lay

[2] Model A = direct genetic effect+year+hatch(year), Model B = Model A + maternal genetic effect, Model C = Model A + permanent environmental effect of dam, Model D = Model A+ maternal genetic effect + permanent environmental effect of dam

$\sigma^2_d$ = direct genetic variance, $\sigma^2_m$ = maternal genetic variance, $\sigma^2_p$ = permanent environmental variance, $h^2_d$ = direct heritability, $h^2_m$ = direct-maternal heritability.

**Table 3-6 Estimated variance components of direct additive genetic, maternal genetic and maternal permanent environmental effects for egg production traits in the WPR line**

| Traits[1] | Model[2] | Variance components | | | Genetic parameters | | |
|---|---|---|---|---|---|---|---|
| | | $\sigma^2_d$ | $\sigma^2_m$ | $\sigma^2_{pe}$ | $h^2_d$ | $h^2_m$ | $h^2_{pe}$ |
| AFE | A | 54.12 | | | 0.44 | | |
| | B | 51.03 | 2.64 | | 0.42 | 0.02 | |
| | C | 51.14 | | 2.72 | 0.42 | | 0.02 |
| | D | 50.53 | 1.35 | 1.83 | 0.41 | 0.01 | 0.02 |
| BWT | A | 13468.6 | | | 0.44 | | |
| | B | 11462.2 | 1221.88 | | 0.38 | 0.04 | |
| | C | 12479.9 | | 632.16 | 0.42 | | 0.02 |
| | D | 11453.4 | 1222.73 | 0.00 | 0.38 | 0.04 | 0.00 |
| EWFE | A | 5.40 | | | 0.33 | | |
| | B | 5.26 | 0.00 | | 0.32 | 0.00 | |
| | C | 5.34 | | 0.00 | 0.33 | | 0.00 |
| | D | 5.26 | 0.00 | 0.00 | 0.32 | 0.00 | 0.00 |
| EN | A | 43.79 | | | 0.20 | | |
| | B | 43.79 | 0.00 | | 0.20 | 0.00 | |
| | C | 41.55 | | 1.67 | 0.19 | | 0.01 |
| | D | 41.52 | 0.00 | 1.68 | 0.19 | 0.00 | 0.01 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EW | A | 7.04 | | | 0.43 | | |
| | B | 6.21 | 0.59 | | 0.38 | 0.04 | |
| | C | 6.86 | | 0.17 | 0.42 | | 0.01 |
| | D | 6.21 | 0.59 | 0.00 | 0.38 | 0.04 | 0.00 |

[1] AFE = age at first egg, BWT = body weight at first egg, EWFE = egg weight at first egg, EN = total egg number from 1st week to week 17th of lay, EW = average egg weight at week 17th of lay

[2] Model A = direct genetic effect+year+hatch(year), Model B = Model A + maternal genetic effect, Model C = Model A + permanent environmental effect of dam, Model D = Model A+ maternal genetic effect + permanent environmental effect of dam

$\sigma^2_d$ = direct genetic variance, $\sigma^2_m$ = maternal genetic variance, $\sigma^2_p$ = permanent environmental variance, $h^2_d$ = direct heritability, $h^2_m$ = direct-maternal heritability.

**Table 3-7 Estimated variance components of direct additive genetic, maternal genetic and maternal permanent environmental effects for egg production traits in the RC line**

| Traits[1] | Model[2] | Variance components | | | Genetic parameters | | |
|---|---|---|---|---|---|---|---|
| | | $\sigma^2_d$ | $\sigma^2_m$ | $\sigma^2_{pe}$ | $h^2_d$ | $h^2_m$ | $h^2_{pe}$ |
| AFE | A | 31.46 | | | 0.37 | | |
| | B | 30.70 | 0.50 | | 0.36 | 0.01 | |
| | C | 29.72 | | 1.78 | 0.35 | | 0.02 |
| | D | 29.72 | 0.00 | 1.78 | 0.35 | 0.00 | 0.02 |
| BWT | A | 12376.2 | | | 0.40 | | |
| | B | 11578.5 | 589.34 | | 0.38 | 0.02 | |
| | C | 11201.3 | | 1013.56 | 0.37 | | 0.03 |
| | D | 11200.5 | 0.42 | 1012.92 | 0.37 | 0.00 | 0.03 |
| EWFE | A | 9.27 | | | 0.38 | | |
| | B | 9.11 | 0.20 | | 0.37 | 0.01 | |
| | C | 9.09 | | 0.31 | 0.37 | | 0.01 |
| | D | 9.04 | 0.13 | 0.21 | 0.37 | 0.01 | 0.01 |
| EN | A | 25.08 | | | 0.18 | | |
| | B | 23.98 | 0.84 | | 0.17 | 0.01 | |
| | C | 19.14 | | 4.74 | 0.14 | | 0.03 |
| | D | 19.17 | 0.00 | 4.74 | 0.14 | 0.00 | 0.03 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EW | A | 7.92 | | | 0.40 | | |
| | B | 7.21 | 0.61 | | 0.36 | 0.03 | |
| | C | 7.10 | | 0.98 | 0.36 | | 0.05 |
| | D | 7.10 | 0.00 | 0.98 | 0.36 | 0.00 | 0.05 |

**1** AFE = age at first egg, BWT = body weight at first egg, EWFE = egg weight at first egg, EN = total egg number from 1st week to week 17th of lay, EW = average egg weight at week 17th of lay

2 Model A = direct genetic effect+year+hatch(year), Model B = Model A + maternal genetic effect, Model C = Model A + permanent environmental effect of dam, Model D = Model A+ maternal genetic effect + permanent environmental effect of dam

$\sigma^2_d$ = direct genetic variance, $\sigma^2_m$ = maternal genetic variance, $\sigma^2_p$ = permanent environmental variance, $h^2_d$ = direct heritability, $h^2_m$ = direct-maternal heritability.

**Table 3-8 Estimated variance components of direct additive genetic, maternal genetic and maternal permanent environmental effects for egg production traits in the WC line**

| Traits[1] | Model[2] | Variance components | | | Genetic parameters | | |
|---|---|---|---|---|---|---|---|
| | | $\sigma^2_d$ | $\sigma^2_m$ | $\sigma^2_{pe}$ | $h^2_d$ | $h^2_m$ | $h^2_{pe}$ |
| AFE | A | 47.14 | | | 0.46 | | |
| | B | 45.24 | 2.33 | | 0.44 | 0.02 | |
| | C | 46.45 | | 2.67 | 0.45 | | 0.03 |
| | D | 46.11 | 0.50 | 2.38 | 0.46 | 0.01 | 0.02 |
| BWT | A | 13454.3 | | | 0.53 | | |
| | B | 13311.2 | 171.74 | | 0.53 | 0.01 | |
| | C | 13458.8 | | 4.30 | 0.53 | | 0.00 |
| | D | 13305.0 | 171.11 | 0.00 | 0.53 | 0.01 | 0.00 |
| EWFE | A | 7.18 | | | 0.36 | | |
| | B | 6.88 | 0.39 | | 0.34 | 0.02 | |
| | C | 7.19 | | 0.00 | 0.36 | | 0.00 |
| | D | 6.88 | 0.39 | 0.00 | 0.34 | 0.02 | 0.00 |
| EN | A | 24.32 | | | 0.38 | | |
| | B | 24.32 | 0.00 | | 0.38 | 0.00 | |
| | C | 22.86 | | 1.66 | 0.36 | | 0.03 |
| | D | 22.86 | 0.00 | 1.66 | 0.36 | 0.00 | 0.03 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EW | A | 7.84 | | | 0.45 | | |
| | B | 7.84 | 0.00 | | 0.45 | 0.00 | |
| | C | 7.84 | | 0.00 | 0.45 | | 0.00 |
| | D | 7.84 | 0.00 | 0.00 | 0.45 | 0.00 | 0.00 |

[1] AFE = age at first egg, BWT = body weight at first egg, EWFE = egg weight at first egg, EN = total egg number from $1^{st}$ week to week $17^{th}$ of lay, EW = average egg weight at week $17^{th}$ of lay

[2] Model A = direct genetic effect+year+hatch(year), Model B = Model A + maternal genetic effect, Model C = Model A + permanent environmental effect of dam, Model D = Model A+ maternal genetic effect + permanent environmental effect of dam

$\sigma^2_d$ = direct genetic variance, $\sigma^2_m$ = maternal genetic variance, $\sigma^2_p$ = permanent environmental variance, $h^2_d$ = direct heritability, $h^2_m$ = direct-maternal heritability.

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# Chapter 4. Breeding Objectives for Crossbred Commercial Chicken under a Tropical Climate in Thailand

## 4.1. Introduction

The breeding objectives are the first step to define the appropriate breeding goal as the navigator of a breeding plan. In the layer chicken industry, the breeding objectives can be derived from a mixture of factors related to the producer and consumer demand. The assumption is that the primary goal of producers is to maximize profit (Harris, 1970). Breeding objectives are required to improve the production potential and economic efficiency of layer chickens in an optimal manner based on multiple trait selection (van der Werf, 2013a). The breeding goals of layers have largely been unchanged in the last decade (Goger, Yurtogullari, & Demirtas, 2010), comprising improvement of the following traits: decreased age at sexual maturity, increased rate of lay, decreased mature body weight, increased average egg weight, and decreased mortality (Groen, 2003). These egg production traits are important factors determining the profitability of a layer farm. Development of breeding objectives involves the calculation of economic values for all biological traits that have an impact upon profitability (James, 1982). The economic outcome of a breeding plan is derived though bioeconomical modelling by combining revenue and cost for a defined production system. Unit changes in marginal return and marginal cost arising from improvement of a trait, and partial differentiation of the profit functions with respect to the trait of interest are the two methods used to calculate economic values.

The current commercial layer chicken breeds in the world are the product of the implementation of many generations of selection (Alshami, 2014). These commercial chickens and their parents are imported by commercial layer producers to increase layer productivity in Thailand. This importation of day-old chicks and other poultry products carries substantial risks of introducing diseases from the importing countries. One such incident was the major outbreak of avian influenza infection (AI) in 2004. This outbreak of AI resulted in an economic loss of AUD 357 million to the Thai poultry industry as a result of the banning of imported and exported chicks, egg and egg products (Avian Influenza Control Center, 2006). In order to sustain the layer industry, the Department of Livestock Development in Thailand (DLD) developed a crossbred layer chicken by establishing two pure lines (RIR and WPR) and two hybrid lines, RC and WC, and distributed these to small-scale commercial layer producers. Two pure and two hybrid lines were established based on the fact that line breeding with different selection strategies increase heterosis and complementarities in crossbred commercial layers while improving the traits with antagonistic relationship by selecting in different lines (Chao & Lee, 2001; Yang & Jiang, 2005). RIR and WPR lines were established because they were selected for longer than 40 years under Thai condition. Therefore, they were well adapted to the poultry management conditions in Thailand. However, the egg production traits, such as egg number and egg weight, of crossbred layers are lower than the less adapted exotic layer breeds. A recent evaluation of the performance of these hybrid chicken revealed that both of the hybrid layer birds had a survival rate of more than 85% up to a year of lay and produced 260 eggs per year (71% rate of lay) under rural poultry management conditions in Thailand (Sopha et al., 2012). There is a need to improve the productivity of these crossbred chickens. Therefore, the aim of this chapter was to develop breeding objectives for the crossbred layer chickens and based on the derived economic values predict the potential genetic gain in the two hybrid lines and in the crossbred chickens. This study also compared the genetic gain in the two hybrid lines by applying a strategy where both lines have the same breeding objective traits with the same economic weights with a scenario where two lines are selected divergently and hence have different breeding objectives.

## 4.2. Materials and Methods

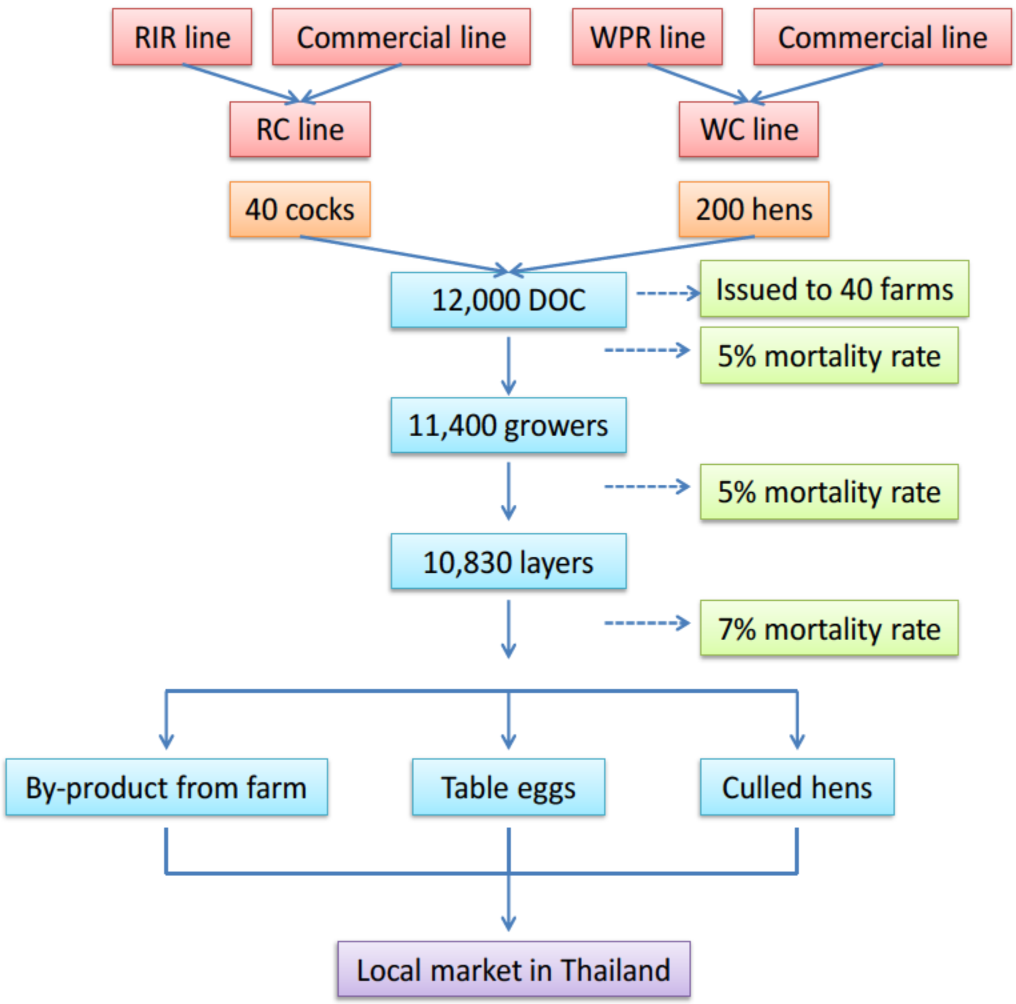
The breeding objective was defined for the following economically important traits: age at first egg (AFE), body weight at first egg (BWT), rate of lay (RL), average egg weight (EWT), and survival rate (SUR). These traits contribute to profit by the sale of eggs at optimal market weight and culled layer birds at the end of lay. Feed intake (FI) is another trait that has a significant influence on the profit of commercial egg production. However, it was not feasible to measure FI in commercial or in parent lines. Therefore, BWT was used to indirectly account for FI.

AFE is the age of the hen when she starts to lay her first egg. AFE determines the length of egg production and, thereby, the number of eggs produced by a hen. A hen that starts to lay earlier will produce a larger number of eggs and thereby increase the income from the sale of eggs. BWT is the weight of the hen when she lays her first egg. BWT is related to feed consumption. Hens with heavier body weight at maturity have higher maintenance requirements. Therefore, hens with heavier BWT have higher FI than hens with lower body weight and, thereby, reduce profitability of the enterprise even though they get a slightly higher income from live weight culled hens. Furthermore, BWT has a positive correlation with AFE. This means a hen with higher BWT starts to lay later than a hen with lower BWT and lays fewer eggs. RL is defined as the number of egg produced by a hen from onset of lay to the end of a defined laying period as a percentage of the number of days in that period. Rate of lay has a direct influence on the income as it determines the number of eggs produced. Egg price in Thailand is based on egg weight. Eggs are currently graded into six weight classes. The heaviest eggs weighing 65 to 70 g get the highest prices (2.88 THB). Therefore, eggs with a higher weight will improve profitability. SUR is the proportion of chicks that survived from one-day-old chicks to the end of lay. This trait is related to disease resistance, resilience and robustness of the chicken. High SUR leads to high productivity and reduced veterinary-related expenses. Therefore, higher SUR increases profitability.

Income from and cost of crossbred commercial chickens were calculated and the profits were derived from this. Economic values for the five traits were derived from the change in profit after one unit improvement in a trait, assuming all other traits remained constant (Gibson, 2013). Response to selection was predicted for a selection index using newly developed economic weights and the genetic gain was examined for each of the lines as well as for the resulting crossbred layer chickens.

### 4.2.1. Production model

The model used in the production of commercial layer chickens is given in Figure 4-1. Two hybrid lines, namely RC and WC, were maintained. Each line had 200 breeding hens and 40 breeding cocks. Two hundred breeding hens from the WC lines were mated with 40 cocks from the RC lines (mating ratio of 1:5) to produce 12,000 female day-old commercial chicks. Each hen had 60 female chicks and the male chicks were destroyed at the time of hatch. The female day-old chicks were sold to commercial layer producers. Eggs produced from the hens were sold as table eggs and at the end of the production period, the hens were sold as culled chicken.




**4-1 Production of commercial layer chicken at the Department of Livestock Development of Thailand**

### 4.2.2. Economic models

Mean performances of the commercial hens for the five traits were calculated using the mean performances of the two hybrid lines and heterosis for each trait as given in Table 4-1. The formula to compute mean performance of commercial chicks as:

Mean performance of commercial chick = $(0.5*P_1) + (0.5*P_2) + (0.5*H)$

Where $P_1$ and $P_2$ are the trait means of WC and RC lines, respectively. H is the heterosis effect of each trait as measured in the first cross. Both RC and WC are hybrid lines which were produced by crossing a brown-egg-laying commercial strain to RIR and WPR, respectively. Thereby, the amount of heterosis expressed in the commercial chicks is 0.5*H.

**Table 4-1 Mean performance of RC and WC hybrid lines along with published heterosis percentage for the five objective traits**

| Line | Traits[1] | | | | |
|---|---|---|---|---|---|
| | AFE (day) | BWT (kg) | RL (%) | EWT (g) | SUR (%) |
| RC | 163 | 1.8 | 85 | 53 | 82 |
| WC | 163 | 1.6 | 88 | 52 | 83 |
| Heterosis[2] (%) | -2.5[a] | 2.6[a] | 8.2[a] | 2.1[a] | 2.0[b] |

[1] AFE, age at first egg; BWT, body weight at first egg; RL, rate of lay for first 17 weeks of lay; EWT, average egg weight at 17th weeks of lay; SUR, survival to onset of lay

[2] Heterosis values were from [a] Bordas, Merat, and Minvielle (1996) and [b] Fairfull (1990).

Trait means that were used in the economic model to calculate income and cost are given in Table 4-1. Income and cost were then used to calculate profit by taking the difference between these components. The birds' life cycle was separated into three periods by age, namely, starter period

(0 to 6 weeks), grower period (7 to 16 weeks) and layer period (17 to 72 weeks). Total cost, income, and profit were computed for 40 flocks each with 300 crossbred hens per flock for one cycle of production. Production costs included day-old chicks, management, electricity, water, feed, labour, veterinary, and marketing costs. Selling table eggs and culled birds were the main income of the commercial operation. The cost and income for economic variables were based on the government price implemented during the study period. The prices were in Thai baht (THB), where one Australian dollar was equal to 30 THB. The original costs were reduced by an inflation rate of 3.07% (International Monetary Fund, 2013).

#### *4.2.2.1. Revenue*

Revenue for the commercial layer enterprise was generated by selling table eggs and culled layers. Eggs were sold as fresh eggs based on a grade size system. The egg price was averaged from 2003 to 2012 on six grades ranging from 1 to 6, (Department of Internal Trade of Thailand, 2013) as given in Table 4-2. Culled layers were sold at 35 THB per kg.

**Table 4-2 Egg grade and average egg price in Thailand between 2003 and 2012**

| Egg grade | Egg weight (g) | Price/egg (THB)[1] |
|---|---|---|
| 1 (Extra-large) | 65 - 70 | 2.88 |
| 2 (Large) | 60 - 65 | 2.74 |
| 3 (Medium) | 55 - 60 | 2.61 |
| 4 (Small) | 50 - 55 | 2.53 |
| 5 (Peewee) | 45 - 50 | 2.36 |
| 6 (Smallest) | 40 - 45 | 2.00 |

[1]Prices obtained from Department of Internal Trade of Thailand (2013).

*Table eggs*

The revenue from selling table eggs ($EGG_{ta}$) was computed as follows:

$$EGG_T = \sum [(DOC * (SUR/100)) * ((RL/100)* (Prod – AFE)) x \{((P_1/100) * S_1) + ((P_2/100) * S_2) + ((P_3/100) * S_3) + ((P_4/100) * S_4) + ((P_5/100) * S_5) + ((P_6/100) * S_6)\}]$$

Where $EGG_T$ is the income generated by the sale of eggs, DOC is the number of day-old chicks purchased, SUR is the survival rate of DOC until the end of the production cycle expressed as a percentage, Prod is the length of a production cycle (72 weeks for this study), AFE is the age at first egg, $P_1$ to $P_6$ are the percentage of eggs in each of the six egg grade categories, and $S_1$ to $S_6$ are the price of eggs in each of the six categories. $P_1$ to $P_6$ were simulated using a normal distribution with the mean of 53 g of EW and a standard deviation of 4. The highest proportion of egg grade category simulated was for egg grade 3 (42%) followed by egg grade 4 (37%). Egg grade 2 was 12% of all eggs produced. Then new proportions ($P_1$ to $P_6$) were derived for a normal distribution using the same threshold values for price differentiation, but with a mean EW of 54

*Culled hens*

All layer hens at the end of their production period (18 months of age) were sold as stew hens. Income generated by the sale of culled hens was calculated as:

$$Cull_T = (DOC \times (SUR/100)) * Cull_{BW} * Cull_P$$

Where DOC is the number of day-old chicks purchased, SUR is the survival rate of DOC (83%) until the end of production cycle at 18 months of hen' age and all hens are culled, $Cull_{BW}$ is the live weight of hens at end of production (kg), and $Cull_P$ is the price of culled hens which was assumed as 35 THB/kg of live weight hens.

*By-product*

Poultry litter was sold as a by-product (ByProd) and the income generated from its sale was calculated as:

$$ByProd = N_{Byprod} \times ByProd_p$$

Where $N_{Byprod}$ is the number of bags of fertilizer sold. $ByProd_p$ is the sale price of a bag of fertilizer (30THB/bag) and this income was constant and is not related to trait mean changes.

#### *4.2.2.2. Cost of production*

*Fixed cost*

The fixed cost ($Fix_{cost}$) was computed based on the number of units of housing or equipment, price per unit, depreciation per year, and length of usage per period. This included costs associated with brooder houses, deep litter houses, heaters, fans, and battery cages. The cost was estimated as:

$$Fix_{cost} = \text{total value for units x \%depreciation value}$$

A depreciation value of 10% was assumed for buildings and 15% for equipment. The fixed cost was about 4% of total cost in this crossbred operation.

*Veterinary cost*

The veterinary cost ($Vet_{cost}$) is focused on the vaccination treatments per flock. It was calculated by accumulating the veterinary cost over three periods (starter, grower and layer):

$$Vet_{cost} = (DOC/\ N_{vacd}) \times Vac_p$$

Where $N_{vacd}$ is the dose number per vaccine bottle and $Vac_p$ is the price per bottle of vaccine (THB). All birds were vaccinated several times as recommended by the Department of Livestock Development in Thailand program. Vaccinations were for Marek’s disease, Newcastle disease (ND), infectious bronchitis disease (IB), fowl pox disease, and fowl cholera disease.

*Labour cost*

Labour cost ($Lab_{cost}$) is estimated based on the number of man-hours required to manage the chickens from day-old to end of laying. The $Lab_{cost}$ was separately computed for each period and was:

$$Lab_{cost} = (Lab_{pd} / Hour_{wt}) \times (N_{lab} \times N_{time})$$

Where $Lab_{pd}$ is the labour charge per day (THB), $Hour_{wt}$ is the working hours per day (8 hours), $N_{lab}$ is the number of labourers required for the job, and $N_{time}$ is the number of hours which a labourer worked. Labour charges for the operation were assumed as 200 THB per manual worker per day, which was based on two labourers per 20,000 birds, as recommended in the Thailand Egg Board Agreement (2007), and average labour cost was 15 THB per bird.

*Feeding cost*

The feeding cost ($Feed_{cos}$) was computed based on the metabolizable energy requirement per bird. Total metabilizable energy (ME) requirement of chickens was calculated as per the equation of NRC (1994) in which:

$$ME = W^{0.75} (173-1.95T) + 5.5\Delta w + 2.07EE$$

Where $W$ is body weight (kg), $T$ is the ambient temperature (°C), $\Delta w$ is change in body weight within a growing period (g/day), and $EE$ is daily egg mass (g).

Feed intake for hens was then determined based on ME content of different rations. The feed cost at different growth stages was calculated as:

$$Feed_{cos} = [(ME / \text{ME per kg of current energy rations}) \times N_C \times L_{day})/1000] \times Feed_p$$

Where $N_c$ is the number of chickens, which was related to survival rate in each period; $N_c$ was estimated as $N_C = DOC*SUR_{s/g/l}/100$, where $SUR_{s/g/l}$ is the survival rate of starter (s) or grower (g) or layer (l) period; $L_{day}$ is the length of the production period (days per whole period which includes starter, grower, and layer period); and $Feed_p$ is the price per kg (THB).

$Cull_{pul}$ was estimated as $Cull_{pul} = N_{pul}$-HH where $N_{pul}$ is the number of available pullets, which was calculated as $N_{pul} = N_{grow}$ x (1- ($Mor_{grow}$/100), where $N_{grow}$ is the number of chickens which moved from starter period to grower period and $Mor_{grow}$ is the mortality rate of chickens in the grower period.

### *4.2.2.3. Profitability*

The profit was calculated for the whole production system as outlined in Figure 4-1. It was calculated as total income minus total cost for the whole production period from starter, through grower and layer periods (18 months of hen age) and the profit was on one production cycle. The cost was adjusted according to the average inflation rate before calculating the profitability.

$$\text{Profitability} = \text{Prod}_{income} - \text{Var}_{cost}$$

Where $Prod_{income}$ is the total income of production, which includes income from sale of table eggs, culled hens, and by-product from farm ($Egg_T + Cull_T$ + ByProd); and $Var_{cost}$ is the total cost of variable, which is reduced by the inflation rate (3.07%). Total cost includes day-old chick cost, feed cost and management cost, building and equipment, labour, vaccination and drugs, and electricity and water, (DOC + $Feed_{cost}$ + Management cost).

### 4.2.3. Sensitivity analysis

The impact of change in price levels of feed cost, management cost, price of day-old chicks, price of eggs, and price per culled bird on the economic values was studied using sensitivity analysis. Sensitivity analysis provides information about possible alternative scenarios, and therefore about the range of outcomes, that may be expected. It also shows how the economic values, and therefore breeding objective, is sensitive to assumptions about certain parameters. It has important implications for practical breeding programs (Groen, 2003; Kosgey, 2003). Changes of ± 25% to the original price levels of feed and egg were considered whilst maintaining the same number of hens in the system. Changes were made to one variable at a time, whilst keeping all other parameters constant.

### 4.2.4. Definition of breeding objectives in parent stocks

Two different scenarios were tested. In the first scenario, the same five traits were considered in the breeding objectives for both RC and WC lines. In the second scenario, different breeding objectives were implemented between male and female lines. The WC line was considered as the female line and only included AFE, RL and SUR as traits in the breeding objective with the aim of reducing age at sexual maturity, improved egg number, and survivability. The RC line was considered as the male line with only BWT, EW, and SUR traits in the breeding objective with the aim of reducing bodyweight at sexual maturity, increased egg weight, and survivability.

### 4.2.5. Selection index and response

Response to selection of hens was calculated using a multi-trait selection index using phenotypic information on AFE, BWT, rate of lay (RL), EW and survival from day-old to end of lay (SUR) as information in the selection process. The response was calculated for a breeding program in the nucleus of each line. Each breeding nucleus consisted of 200 hens mated with 40 cocks. Both males and females were selected after 17 weeks of lay. Ten males from 40 cocks (25%) and 40 female from 200 hens (20%) were selected. Table 4-3 gives the proportion of males and females selected, selection intensity, and the generation interval used in the calculation to predict the response to selection. The realized selection intensity was 1.27 and 1.40 for male and female, respectively. The generation interval was 1 year for both male and female parent stocks by using all-in, all-out management. Data recorded for males was one on his dam, five full-sibs, and 15 half-sibs, and for females there was one of her own performance, one of her dam, four full-sibs, and 15 half-sibs. Table 4-4 shows the genetic and phenotypic correlations among the five traits used to calculate the selection indices. Variance and co-variance matrices used in the calculation of indices were bent to be positive definite. Multiple trait selection index software, MTINDEX, was used to predict the response to selection. This is available from http://wwwpersonal.une.edu.au/~jvanderw/.

**Table 4-3 Proportion of males and females selected, selection intensity, and generation interval used in the calculation of response to selection per year**

| Criterion | Male | Female |
|---|---|---|
| Proportion selection, % | 25 | 20 |
| Selection intensity, i | 1.27 | 1.40 |
| Generation interval, L | 1.00 | 1.00 |

**Table 4-4 Genetic (below diagonal) and phenotypic correlation (above diagonal), heritability (on the diagonal) and phenotypic standard deviation ($\sigma_p$) of the five traits in the multiple traits selection index for the hybrid lines**

| **Line** | **Traits** | | | | | |
|---|---|---|---|---|---|---|
| | $\sigma_p$ | AFE | BWFE | RL | EWT | SUR |
| AFE | 10.69 | **0.37** | 0.16 | -0.14 | 0.20 | [a]*0.20* |
| BWFE | 0.20 | 0.21 | **0.41** | 0.06 | 0.26 | [a]*0.34* |
| RL | 10.49 | -0.20 | 0.04 | **0.18** | -0.22 | [a]*0.10* |
| EWT | 4.76 | 0.36 | 0.42 | -0.63 | **0.36** | 0.01 |
| SUR | [a]*8.9* | [c]*-0.62* | [c]*0.07* | [c]*0.30* | [c]*0.20* | [b]***0.05*** |

All parameter values, except italic number, were from the previous chapter in which the genetic parameters for the five traits were estimated for the two hybrid lines for egg production traits in this project.

Subscripts indicate reference for this parameter: [a] adapted from Alshami (2014), [b]Dempster, Lerner, and Lowry (1952), [c]Fairfull and Gowe (1990).

## 4.3. Results

### 4.3.1. Production and economic model

The results from the production model and profit function are given in Table 4-5 and Table 4-6.

Total cost, income, and profit of crossbred commercial layer chicken are presented in Table 4-5.

Day-old chicks were purchased at a cost of 15 THB per chick, and total cost of day-old chicks was 186,105 THB for all 40 farms. The cost of day-old chicks was 2.57% of the total cost.

The major cost of this poultry operation was feed (86%). Feed intake was recorded throughout, from the starter period until the end of the layer period. However, for the starter period, the highest cost was for management (41%), followed by feed and DOC costs. For the grower and layer periods the majority of the cost was for feed. The total feed consumption of this operation was 38.15 kg per bird. The total feed cost per hen was 517 THB, and the total feed cost for this operation was 6,203,192 THB. This amounted to about 86% of the total cost incurred for this commercial operation.

Management cost was the next major cost and it included vaccinations, electricity and water, labour, fixed costs, other management costs, and the depreciation cost of buildings and equipment. Total management cost was 844,290 THB per flock and was about 11% of the total cost incurred for this operation. Average cost per bird was 603 THB.

Total income generated in this commercial poultry operation was over eight million THB. Income was generated by selling table eggs, culled hens and by-product from farms. The primary income source was the sale of eggs. Ninety-five percent of all eggs produced were sold as table eggs. Dirty eggs and cracked eggs were accounted for by reducing total number of egg by 5%. Egg prices depended on egg grade class (grade 1 to 6). Nearly three million eggs were sold as table eggs. The most popular egg size was grade 3 and accounted for 42% of all eggs sold. Income from selling table eggs was 7.5 million THB, which was about 91% of the total income obtained in this operation. Culling layer stocks after the laying period was the second highest income generator in this operation. Layers reached a body weight of 2.04 kg at the end of their laying period and were sold at 35 THB per kg live weight or 71 THB per bird. Total income from sale of culled birds was 717,245 THB, which was 9% of the total income. Selling poultry litter as fertilizer generated the rest of the income. The overall profit of this operation was 1,063,734 THB (35,457 AUD) and was 88 THB (2.95 AUD) per bird (Table 4-5).

**Table 4-5 Cost, income, and profit for 40 commercial farms, each with 300 crossbred chickens per one production period (72 weeks)**

| Variation | For all farms | Per hen |
|---|---|---|
| **Input variables** | | |
| Birds enter to starter period | 12,000 | |
| Birds enter to grower period | 11,357 | |
| Birds enter to layer period | 10,786 | |
| Birds at complete production | 10,052 | |
| Feed price per kg (THB/kg) | | |
| Starter feed | 14.23 | |
| Grower feed | 12.86 | |
| Layer feed | 13.60 | |
| Mature live weight (kg) | 20,506 | 2.04 |
| Total Feed consumption (kg) | 6,399,662 | 38.15 |
| **Cost for the entire operation** | | |
| Cost of day-old chicks (THB) | 186,105 | 15.51 |
| Cost of feed intake (THB) | 6,203,192 | 516.93 |
| Cost of management (THB) | 844,290 | 70.36 |
| Total cost (THB) | 7,233,588 | 602.80 |
| **Income from forty farms** | | |
| Number of table eggs sold (Eggs, 000) | 2,921 | 243 |
| Income from selling table egg (THB) | 7,523,677 | 2.58 |
| Income from selling culled bird (THB) | 717,245 | 71.35 |
| Income from selling by-product from farm (THB) | 56,400 | 30.00 |
| Total income (THB) | 8,297,322 | 691.44 |
| **Profit for the entire operation** | | |
| Profit (THB) | 1,063,734 | 88.64 |
| | (35,457AUD) | (2.95 AUD) |

### 4.3.2. Derivation of economic weights

The economic weights of five egg-production traits were derived using the production model and the profit function as indicated above. Table 4-6 gives the economic weight for AFE, BWT, RL, EW, and SUR traits as per a unit change in each trait. The highest economic weight of 0.23 AUD was obtained for RL and was equal to the price of three eggs. Economic weights for egg weight and survival rate were positive and very similar for both traits. One day's delay in the onset of lay reduced the profit per hen by 0.06 AUD, and 1 g increase in body weight reduced the profit by 0.57 AUD.

**Table 4-6 The economic weight for breeding objective traits**

| Traits | Economic weight (AUD)/unit/bird/round production |
|---|---|
| AFE | -0.06 |
| BWT | -0.57 |
| RL | 0.23 |
| EW | 0.18 |
| SUR | 0.20 |

Note: Calculated per trait per unit of improvement per bird in a crossbred production system

### 4.3.3. Sensitivity analysis

Economic values derived from change in profit for a 25% increase or decrease in feed cost and egg price are given in Table 4-7.

*Feed cost*

As expected, price variation for feed influenced economic weights for BWT and SUR. A 25% decrease in feed price increased the economic weights of BWT and SUR, while a 25% increase in feed price decreased the economic weight of BWT and SUR.

*Egg price*

Variation for egg price did not change the economic weight of BWT. However, a 25% decrease in egg prices reduced the economic weights of AFE, RL, EW and SUR, while a 25% increase in egg price increased the economic weights of AFE, RL, EW and SUR.

**Table 4-7 Profit and economic weight for increasing and decreasing the cost and price of variations by 25% (AUD)**

| Variable | Change | Profit/hen | Economic weight | | | | |
|---|---|---|---|---|---|---|---|
| | | | AFE | BWT | RL | EW | SUR |
| Base | | 2.95 | -0.06 | -0.57 | 0.23 | 0.18 | 0.20 |
| Feed cost | 25% | -1.35 | -0.06 | -0.71 | 0.23 | 0.18 | 0.18 |
| | -25% | 7.26 | -0.06 | -0.43 | 0.23 | 0.18 | 0.21 |
| Egg price | 25% | 8.18 | -0.08 | -0.57 | 0.29 | 0.23 | 0.26 |
| | -25% | -2.27 | -0.05 | -0.57 | 0.17 | 0.14 | 0.14 |

### 4.3.4. Predicted response to selection

Annual response per trait in unit terms and monetary values by using the selection intensities given in Table 4-4 is given in Table 4-8. When implementing the same breeding objective for both hybrid lines, annual responses for RL and SUR were positive for RC, with RL having the highest monetary value of 0.65 AUD per bird per year. While negative responses were observed for AFE and EW, with EW generating the lowest monetary response of -0.17 AUD per bird per year.

For WC, with the same breeding objective as RC, annual responses for RL, EW, and SUR were positive, with RL having the highest monetary response of 0.68 AUD. A negative annual response was observed for BWT with a monetary response of -0.02 AUD.

When different breeding objectives were implemented for the two lines, annual responses of all traits except RL were positive for RC, with the highest monetary value of 0.41 AUD for EW.

For WC, annual responses of RL and SUR were positive. The highest monetary response value of 0.81 AUD was for RL and the lowest monetary response was for BWT and EW.

**Table 4-8 The response to selection in trait units and in monetary value per year for RC and WC lines selected with the same and different breeding objectives**

| Trait | RC | | | | WC | | | |
|---|---|---|---|---|---|---|---|---|
| | Same | | Different | | Same | | Different | |
| | Response per year | AUD value | Response per year | AUD value | Response per year | AUD value | Response per year | AUD value |
| AFE, days | -2.28 | 0.14 | 2.74 | 0.00 | -1.06 | 0.06 | -1.45 | 0.09 |
| BWT, kg | 0.00 | 0.00 | 0.03 | -0.02 | 0.00 | 0.00 | -0.02 | 0.00 |
| RL, % | 2.81 | 0.65 | -1.85 | 0.00 | 2.96 | 0.68 | 3.53 | 0.81 |
| EW, g | -0.94 | -0.17 | 2.27 | 0.41 | 0.09 | 0.02 | -1.13 | 0.00 |
| SUR, % | 0.62 | 0.13 | 0.72 | 0.14 | 0.72 | 0.14 | 0.51 | 0.10 |
| Total | | 0.75 | | 0.53 | | 0.90 | | 1.00 |

#### *4.3.4.1. Predicted mean performance after a year of selection*

Predicted mean performance, after a year of selection using the same five breeding objective traits and using different breeding objective traits in the two hybrid lines, for RC and WC and for the crossbred commercial chicks are given in Table 4-9 and Table 4-10 respectively.

*Using the same breeding objective*

In this scenario, the same numbers of traits with the same economic values were used in both hybrid lines. For RC, predicted means for RL and SUR increased, and means for AFE and EW decreased. The predicted mean for BWT did not change. For WC, predicted means for RL, EW, and SUR increased, while AFE decreased. The predicted mean for BWT did not change. After a year of selection, mean performance of WC for all five traits, except BWT, were higher than those of RC.

One cycle of selection per year in the two hybrid lines resulted in a 3% increase in RL, 1% increase in SUR, 2 days reduction in AFE, and 0.4 g reduction in EW of the crossbred commercial chicks compared to the current performances (Table 4-10). BWT did not change. Changes in the means of the objective traits increased the profit per bird by 0.97 AUD per year from the current level.

*Using different breeding objective traits*

For RC, predicted means for all traits, except RL, increased. For WC, predicted means of RL and SUR increased, while the means of AFE, BWT, and EW decreased. This resulted in lower means of AFE, BWT, and EW than those of RC.

A year of selection, with different breeding objectives in the two hybrid lines, resulted in a 0.92% increase in RL, 0.63 g increase in EW, 0.6 days increase in AFE and a 0.05% reduction in SUR of the crossbred commercial chicks compared to the current performances (Table 4-10). This increased the profit per bird by 0.50 AUD from the current level. However, the increase in the profit observed by implementing different breeding objective traits was less than the profit obtained by implementing the same breeding objective traits.

**Table 4-9 Mean performance after one cycle of selection per year in RC and WC lines using the same and different breeding objectives**

| Trait | RC | | | WC | | |
|---|---|---|---|---|---|---|
| | Current | Same | Different | Current | Same | Different |
| AFE, day | 163.00 | 160.70 | 165.74 | 163.00 | 161.90 | 161.55 |
| BWT, kg | 1.80 | 1.80 | 1.83 | 1.60 | 1.60 | 1.58 |
| RL, % | 85.00 | 87.81 | 83.15 | 88.00 | 90.96 | 91.53 |
| EW, g | 53.00 | 52.00 | 55.27 | 52.00 | 52.09 | 50.87 |
| SUR, % | 82.00 | 82.60 | 82.72 | 83.00 | 83.72 | 83.51 |

**Table 4-10 Predicted mean performance of crossbred flock after one cycle of selection per year using the same and different breeding objectives**

| Trait | Current | Selection system | |
|---|---|---|---|
| | | Same | Different |
| AFE, day | 161.00 | 159.30 | 161.60 |
| BWT, kg | 1.72 | 1.72 | 1.73 |
| RL, % | 90.00 | 93.04 | 90.92 |
| EW, g | 53.00 | 52.62 | 53.63 |
| SUR, % | 83.00 | 84.00 | 83.95 |
| Profit/hen, AUD | 2.95 | 3.92 | 3.45 |

## 4.4. Discussion

The aim of this study was to develop selecting strategies to improve the production potential of layer chicks produced by the Department of Livestock Development in Thailand for commercial poultry production systems. Two different selection strategies were compared in terms of genetic response and monetary value. One used the same objective traits and economic values in both hybrid lines, and the other used different breeding objectives for the two hybrid lines. A second strategy was explored to account for the antagonistic relationship observed between RL and EW. Breeding objectives should be directed towards the production system that the genetic improvement program is intended for (Ponzoni, 1986). Five breeding objective traits, which play a major role in the profitability of small-scale (<500 birds) commercial poultry production in Thailand, were identified for use in this study. A particularly important consideration was survivability as this plays a significant role in the profitability of birds managed in open houses in a tropical environment. The number of traits considered in this study was less than the number of traits considered by Flock, Laughlin, and Bentley (2005) because the poultry improvement program at the Department of Livestock Development is still at an early stage, and limited number of traits were recorded for the last ten years. A production model, representing commercial chicken production in Thailand was developed to derive profit and economic values for the five breeding objectives traits.

A derived profit of 2.95 AUD per bird and a profit per egg of 0.06 AUD from the production model were within the range estimated for small-scale commercial poultry operations in Thailand (Poapongsakorn et al., 2003). Estimated positive economic values for RL, EW, and SUR suggest that genetic improvement of these three traits would improve the profitability of small-scale commercial layer producers. Negative economic values for AFE and BWT suggest that genetic improvement should be aimed at reducing the AFE by a day to improve the profitability by 0.06 AUD per bird and reducing the BWT of hens by 1 g to improve profitability by 0.57 AUD per bird. Hogsett and Nordskog (1958), and Kempthorne and Nordskog (1959) reported positive economic values for EW and RL and the negative economic weight of BWT was 0.25 AUD lower than the value reported in this study. Currently the egg prices are based on egg weight classes and egg weight of more than 54 g tended to attract a premium in the market (Bureau of Feed Maketing and Animal Plan, 2015). A positive economic weight for EW suggests that further improvement in EW increases the profitability of the small-scale commercial poultry farm. Fluctuation in prices of input and output variables may change the estimated economic weights of the five breeding objective traits.

As expected, the fluctuation in feed cost and egg price had a bigger influence on the estimated economic weight of the five breeding objective traits. Increasing or decreasing the feed cost had a significant influence on the economic weight of BWT with a 0.14 AUD increase or decrease from the base economic value for BWT (Jiang, Groen, & Brascamp, 1998). SUR was also influenced by the change in feed price.

Change in egg prices influenced the economic weight of all traits, except for BWT. Profit after 1 g increase in body weight was not influenced by the change in egg weight prices. However, change in egg prices altered the economic weight of AFE, RL, EW, and SUR by 0.01 AUD, 0.06 AUD, 0.04 AUD, and 0.05 AUD, respectively. The same trends were observed by Fairfull and Chambers (1984) and Yusuf and Malomo (2007) when increasing the feed prices for layer chickens.

Line breeding is an accepted breeding strategy in layer poultry breeding. Specialized lines for egg production and egg weight are maintained, and crossing these specialized lines yields optimum profitability in crossbred commercial layers (Chao & Lee, 2001; Yang & Jiang, 2005). Heterosis and complementarity were explored by monitoring separate lines with different selection strategies to account for the antagonistic nature of some of the egg production traits. Furthermore, line breeding is beneficial when lines have variation in traits which are differentially selected. This may support the implementation of different breeding objectives for different lines. In this study, the WC line was superior or equal for all five traits to the RC line. Furthermore, currently these lines are selected with the same emphasis. Therefore, including different traits in their breeding objectives in this study was not economically beneficial compared to implementing the same breeding objectives for both lines. A multi-trait selection index with the same breeding objective traits for both hybrid lines could be used to improve the productivity of the commercial layer chicks produced by the Department of Livestock Development in Thailand. Selection based on the above multiple traits selection is expected to improve all traits in both lines, except EW in RC. The RL, EW, and SUR were economically important traits for small-scale commercial poultry operation in Thailand. A year of selection using a multiple traits index yielded means of 88% and 52g for RL and EW, respectively, in RC, and 91% and 52 g for the same traits, respectively, in WC. Those means were higher than the means reported for the same traits of RC and WC by Indraramongkhon et al. (2007). Using the above multiple traits index improved means of all traits, except for RL, by less than 1% of their mean and this is within the range published by Smith (1984) for poultry. However, the genetic gain of 3% for RL was slightly higher than the published values. The above changes yielded higher profit per crossbred hen (AUD 3.92) by using same breeding objectives than using different breeding objectives for the two hybrid lines.

## 4.5. Conclusions

Economic weight derived in this study indicates that improved profit can be achieved for commercial layer operations by increasing rate of lay, average egg weight and survival ability, and decreasing age at sexual maturity and body weight of hens. Fluctuation in feed cost and market egg price is expected to have a big influence on the profit of small-scale commercial layer production in Thailand. Selecting two hybrid lines using the same objective traits, yields a greater genetic response and higher profit for small-scale poultry producers than using different objective traits. However, further investigation is warranted to explore the advantage of using specialized lines when index weights are optimized in both lines.

# Chapter 5. General Discussion and Conclusions

## 5.1. General discussions

This thesis explored the options for genetically improving the performance of small scale commercial layer production in Thailand. Egg producers in Thailand prefer birds with brown feathers and egg shells (Kaleta & Redmann, 2008). Day-old chick producers need chicks that can be sexed using their feather structure. The White Plymouth Rock breed has the sex linked gene (Bitgood & Shoffner, 1990) which can be used to feather sex chicks at hatch. Therefore, in 2004, Department of Livestock Development in Thailand initiated a brown egg laying layer chicken breeding program with the aim of improving layer chicken productivity under commercial and backyard poultry production systems. Two pure lines (RIR and WPR) and two hybrid lines (RC and WC) were established and maintained by the Department of Livestock Development with the assumption that selected parent stocks could be disseminated to commercial and backyard poultry producers. This emphasizes the need to design an appropriate breeding program to improve the performances of pure and hybrid lines by developing appropriate breeding objectives. However, formal breeding objectives are yet to be developed for the two pure lines and the two hybrid lines. Therefore, the overall aim of this study was to estimate genetic parameters for economically important traits, to develop breeding objectives for the hybrid lines, and to predict rates of genetic improvement using the genetic parameters and indexes based on the derived economic values.

### 5.1.1. Genetic parameters for the pure and hybrid lines

Accurate estimates of the genetic and phenotypic (co) variance components for economically important traits are required to develop an efficient selection scheme to maximize genetic improvement of selected traits (Falconer & MacKay, 1996). Ten generations of phenotypic records for AFE, BWT, EWFE, EN and EW were used in univariate and bivariate linear animal model evaluations to estimate genetic parameters and correlations. Among the two pure lines, means of EWFE, EN and EW were higher in RIR compared to WPR, as observed by Monira et al. (2003). Among the two hybrid lines, RC line had higher means for EWFE and EW than the WC line. Based on phenotypic performance observed for the four lines, it could be suggested that the RIR line and the hybrid line, RC, could be used as male lines for producing crossbred chicks for backyard and commercial poultry system, respectively. However, due to the nature of the sex linked feather sexing gene, the line with the WPR genotype need to be maintained as the female line. This emphasizes the need for further improvement of egg production in WPR and WC lines to establish their role as female lines in the crossbreeding program.

Higher phenotypic performances of the hybrid lines compared to the pure lines suggests that crosses from these lines could be issued to small-scale commercial farmers while crosses from the pure lines could be issued to backyard poultry producers. Since backyard poultry production is based on low input low out system.

Direct additive genetic effects had a strong influence on all five traits in all four lines with moderate heritability. Since layer chicks are raised independently from their dams, maternal and maternal permanent environmental effects had minimal or negligible effect on most of the traits as observed by Prado-Gonzalez et al. (2003). Estimated heritabilities for the five traits were very similar to the estimates reported for the same traits in chicks raised in environmentally controlled houses in a temperate climate (Francesch et al., 1997; Nurgiartiningsih et al., 2002; Siegel, 1961; Wei & van der Werf, 1995) and in open houses in tropical and semi-arid condition (Niknafs et al., 2012; Sang et al., 2006; Savegnago et al., 2011). Moderate heritabilities combined with a significant amount of genetic variation suggest that selection can be used to improve the performances for all five traits in the pure as well as in the hybrid lines.

AFE had positive genetic and phenotypic correlations with all traits except EN. Estimated genetic correlations were low to moderate ranging from 0.16 to 0.45. Estimated correlations between AFE and BWT, EW and EN were within the ranges in the literature. (El-Labban et al., 2011; Lwelamira et al., 2009; Sang et al., 2006). Estimated genetic correlations suggest that selection for lower AFE could reduce BWT and EW, and increase EN through correlated response. Birds with late sexual maturity will have a heavier body weight at first egg and consume more feed than birds with early maturity. This could result in increased feed costs for the hen. In contrast, birds with late sexual maturity will lay heavier eggs than birds with early maturity (Koutoulis et al., 1997). Hens with early sexual maturity will have light body weight higher egg production but low egg weight.

Genetic correlations between BWT and egg weights (EWFE and EW) were positive for all four lines (0.13 to 0.40 for BWT and EWFE, and 0.42 to 0.62 for BWT and EW) and were similar to the estimates of El-Labban et al. (2011); Lwelamira et al. (2009) and Wolc et al. (2012). Birds with heavier body weight lay heavier eggs than birds with low body weight and heavier eggs fetch a premium (Bureau of Feed Maketing and Animal Plan, 2015).

Higher positive genetic correlations (0.63 to 0.85) between EWFE and EW indicate that birds that lay heavier eggs at their onset of lay continue to lay heavier eggs during their egg production period. Therefore, selecting birds with higher egg weight at the onset of lay improves the egg weight of the flock as observed by Niknafs et al. (2012) and Sang et al. (2006).

The EN had mostly negative genetic and phenotypic correlation with all other traits in this study Abplanalp (1957); Savegnago et al. (2011) and Wolc et al. (2012) also reported negative correlations between EN and other traits. This suggests that selection for higher EN will decrease AFE, BWT and EW (Khalil, Al-Homidan, & Hermes, 2004). Some of the observed antagonistic relationships among the five traits suggest multiple traits selection index approach is required to improve the production potential of these lines. This will be discussed in the next section.

### 5.1.2. Breeding objectives for genetic improvement

#### *5.1.2.1. Production and economic model*

Marginal returns for economically important traits were calculated using the principles of bio-economic modeling to develop breeding objectives (Ponzoni, 1986). Five economically important traits (AFE, BWT, RL EW and SUR) for layer chicken production were identified based on the demand of consumers and market requirements. The production system described represented the small scale commercial poultry production enterprise in Thailand, which comprised 40 commercial farms each with 300 day-old chicks. In this thesis, the cost of hen per production cycle was within the range of commercial layer production in Thailand (The Association of Hen Egg Farmers Traders and Exporters, 2013) and the profit per hen ($0.95) was similar to the value published by Poapongsakorn et al. (2003) for a small-scale layer operation in Thailand.

The economic values for RL (0.23), EW (0.18), and SUR (0.20) were positive, but for AFE (-0.06) and BWT (-0.57) were negative. Therefore, an increase in RL, EW, and SUR and a decrease in AFE and BWT are desired to improve profit for a small-scale poultry producer. Hunter (1990) also found that economic values for SUR were second to RL. SUR was estimated with the assumption that commercial chicks are housed in individual battery cages as in the two lines. Nevertheless, actual commercial layer farms house multiple birds in each battery cage and that may reduce mean survival in layer chicks (Muir, 1996), and according the phenotypic and genetic variation of the trait might be larger. This would increase the value of survival in the breeding objective; a more of the genetic variation in profit would be due to survival.

#### *5.1.2.2. Response to selection*

Line breeding with different selection strategies, is implemented by the poultry breeding companies to increase heterosis and complementarities in crossbred commercial layers (Chao & Lee, 2001; Yang & Jiang, 2005). EN and EW, with antagonistic relationship, may be improved by selecting in different lines. Furthermore, improvements in the performance of crossbreds are also determined by the type of traits use in the selection of male and female lines. Hunter (1990) found higher genetic gain for EW, when it selected with BWT in a selection strategies, and observed higher responses for AFE and EN when combining AFE and EN in selection strategies.

Two specialized lines are more beneficial for gaining high hybrid vigor in crossbred chicken to optimize profit per hen (Bell & Ernst, 1998). This suggests a male line with higher emphasis on BWT, EW and SUR to ensure that birds with appropriate body weight can convert feed to produce heavier egg weight and survive under tropical conditions, and a female line with higher emphasis on AFE, RL and SUR to ensure early sexual maturity, high egg production and low of mortality rate. This principle was used in this study to implement different selection strategies for the two parent hybrid lines where breeding objectives for the male line were for BWT, EW and SUR, and the breeding objectives for the female line were for AFE, RL and SUR. Genetic progress and profit after one year of selection were higher in the selection strategy which had the same five traits across the two lines. The genetic responses and mean differences were in the two lines for five traits and the magnitude of the antagonistic relationship used in the calculation of index weights and response to selection. Continuous selection for the five traits in both hybrid lines may change the magnitude of correlation, and thereby may reduce the efficiency of this selection strategy. Therefore, a reevaluation of the two strategies is warranted after two generations of selection.

## 5.2. Future selection strategy for small-scale layer production

Mean differences for the five traits in the two lines and the magnitude of the antagonistic relationship observed between EN and EW in the two lines might lead to higher profit where the same breeding objectives were used in both lines. Continuous selection, using the same breeding objectives in both lines may change the antagonist relationship, thereby possibly reducing the efficiency of the selection strategy. Therefore, re-evaluation of the two strategies is required after a few generation of selection with the same breeding objectives. This could be based on more 1) economic modeling work where nonlinear aspects of the profit function are explored 2) genetic modeling of non-additive effects and explore how these change, along with the predicted heterosis in divergent line selection, and 3) re-estimation of genetic parameters with more data and after some years of selection in these lines.

## 5.3. General Conclusions

The aim of the poultry breeding program at the Department of Livestock Development in Thailand was to improve layer productivity in backyard and small-scale commercial poultry production systems. The program sought to obtain self-sufficiency in egg production, while protecting the local layer industry from exotic diseases. Differences observed in the phenotypic performance of the pure and hybrid lines support the current policy of distributing the crosses from the pure lines to low input backyard poultry farmers, and the crosses from the hybrid lines to small scale commercial layer production systems. Estimated variances components and genetic parameters of pure line and hybrid lines suggest that selection could improve the RIR production potential of the pure and hybrid lines. (Fairfull & Gowe, 1990)

Derived economic values from the bio-economic modelling suggest that increasing RL, EW and SUR, and decreasing AFE and BWT improve the production potential of the commercial layer chicks. Genetic response in trait unit and in monetary value suggest that using a single selection strategy for both hybrid lines provides a higher return than using different breeding objectives for the two lines. However, validity of this funding need to be reinvestigated after a few generations of selection and with more advanced theoretical modeling. Using a multi-trait selection index using genetic parameters and economic weight derived from the population is expected to yield maximum genetic response in small-scale commercial poultry operation.

# Chapter 6. References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