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Thieu Ngoc Lan Phuong

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STUDIES OF RARE HUNGARIAN AND VIETNAMESE POULTRY BREEDS WITH SPECIAL REGARD TO PARTRIDGE COLOURED HUNGARIAN CHICKEN AND ITS CROSSBREDS IN CONTINENTAL AND TROPICAL CLIMATES

Written by:
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Studies of rare Hungarian and Vietnamese poultry breeds with special regard to partridge coloured hungarian chicken and its crossbreds in continental and tropical climates

Írta:

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Készült

**a Széchenyi István Egyetem
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Wittmann Antal Növény-, Állat- és Élelmiszer-tudományi
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Elfogadásra javaslom (igen / nem)

(aláírás)

**A jelölt a doktori szigorlaton…………%-ot ért el.
Mosonmagyaróvár, ………………………………**

**………………………..
a Szigorlati Bizottság Elnöke**

**Az értekezést bírálóként elfogadásra javaslom (igen/nem)
Első bíráló (Dr. ………………………………) igen/nem**

(aláírás)

Második bíráló (Dr. ………………………………) igen/nem

(aláírás)

Esetleg harmadik bíráló (Dr. …………………….) igen/nem

(aláírás)

A jelölt az értekezés nyilvános vitáján ……………%-ot ért el.

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A Bírálóbizottság elnöke

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DOI: 10.15477/SZE.WAMDI.2019.003

DOI: 10.15477/SZE.WAMDI.2019.003

TABLE OF CONTENTS

DOI: 10.15477/SZE.WAMDI.2019.003

DOI: 10.15477/SZE.WAMDI.2019.003

ABSTRACT

Indigenous or local breeds make up most of the world's poultry genetic diversity. They play important role in rural economies in all developing and underdeveloped countries, but their number, population size and economical importance have been dramatically decreasing in the developed world, including Europe. Therefore, involving indigenous poultry breeds in sustainable agricultural production - as part of conservation programmes - is highly recommended. The present research work (1) analyses the current status of 14 local Hungarian poultry breeds' population; (2) investigates the adaptation and conservation potential of Partridge Coloured Hungarian chicken (PHc) in the subtropics; (3) examines the performance of crossbreds generated from the crosses of PHc and other chicken breeds (commercial lines, old chickens of either nearby or distant origin); (4) identifies the heterosis in the crosses of PHc and other chicken breeds; and (5) determines the quality characteristics of PHc crossbreds that may be valued by modern consumers. The data of population study were collected from the Research Centre for Farm Animal Gene Conservation (HáGK) and the Association for Hungarian Farm Animal Gene Conservation (MGE). The data of adaptation and crossing studies were obtained from experiments conducted either at HáGK or Thuy Phuong Poultry Research Centre (POREC) and family farms in Vietnam. All Hungarian indigenous chickens were hatched from *in vivo* gene bank of HáGK, while the parental commercial lines (Tetra Harco, Tetra H) and a chicken breed of distant origin (Mia chicken) were provided by Bábolna Ltd. and POREC, respectively. Birds were reared using technology described by MGE. All statistical tests were operated by SPSS software. Based on the results, it can be concluded that the number

DOI: 10.15477/SZE.WAMDI.2019.003

of breeding stocks, effective population size and inbreeding rate are good indicators for a genetic conservation programme; PHc has good adaptability in subtropical regions, thus maintaining PHc populations in the tropics is possible for both conservation and breeding purposes; the crossbreds of PHc as paternal and a commercial egg type line (Bábolna Harco, egg type, mother line) as maternal partner is recommended for practical production; crossing PHc with either near (White Transylvanian Naked Neck chicken) or distant origin (Vietnamese Mia chicken) of the same "indigenous or rare" category may offer further potential for improved production in the offspring.

DOI: 10.15477/SZE.WAMDI.2019.003

ÖSSZEFOGLALÁS

Az őshonos, vagy helyi fajták adják a világ baromfi genetikai géntartalékainak legnagyobb részét. Jelentőségük vitathatatlan a legtöbb fejlődő ország vidéki gazdálkodásában, ezzel szemben a fejlett világban, így Európában is, drámai csökkenés tapasztalható mind a fajták populációlétszámában, mind gazdasági értékükben. Ezért a helyi fajták bevonása a fenntartható mezőgazdasági termelésbe a génmegőrzési programok részeként is szükséges. Az itt bemutatott kutatás célja az alábbiakban foglalható össze: (1) 14 őshonos magyar baromfifajta populációgenetikai elemzése; (2) a fogolyszínű magyar tyúk (PHc) adaptációs és génmegőrzési potenciáljának vizsgálata szubtrópusi körülmények között; (3) a PHc fajtára alapozott, különböző hibrid-szülővonalakkal illetve régi, a PHc-hez genetikailag közelebbi vagy távolabbi tyúkfajtákkal végzett keresztezések vizsgálata; (4) a heterózishatás vizsgálata a PHc-re alapozott keresztezésekben; valamint (5) a PHc keresztezések fogyasztói szempontból fontos minőségi tulajdonságainak leírása. Az állományokkal kapcsolatos vizsgálathoz felhasznált adatok a Haszonállat-génmegőrzési Központ (HáGK) illetve a Magyar Haszonállat-génmegőrző Egyesület (MGE) nyilvántartásából származnak. Az adaptációs és keresztezéses vizsgálatok adatait a HáGK és a Thuy Phuong Baromfikutató Központ (POREC, Vietnam), illetve vietnami családi gazdaságok segítségével gyűjtöttük. Valamennyi vizsgált régi magyar baromfifajta a HáGK in vivo génbankjából származott, a kereskedelmi vonalakat a Bábolna-Tetra Kft., a vietnami keresztezésekhez használt régi fajtát pedig a POREC bocsátotta rendelkezésünkre. A kísérleti csibéket az MGE által összeállított tartástechnológia szerint neveltük. A statisztikai próbákat SPSS szoftverrel végeztem. Az

DOI: 10.15477/SZE.WAMDI.2019.003

eredmények alapján megállapítható, hogy: a tenyészállományok száma (n), N_e és ΔF értékei a génmegőrzési programok jó indikátorai; a fogolyszínű magyar tyúk jól alkalmazkodik a szubtrópusi körülményekhez, ezért fajtatiszta PHc populációk kialakítása szubtrópuson génmegőrzési és tenyésztési célból egyaránt lehetséges; a PHc keresztezések mind apai, mind kereskedelmi tojótípusú (pl. Bábolna Harco) anyai vonalakkal, hasznosak lehetnek a gyakorlat számára; a PHc keresztezése más, „őshonos és ritka" fajtákkal – függetlenül attól, hogy ezek genetikailag közelebb (fehér erdélyi kopasznyakú tyúk) vagy távolabb (vietnami Mia tyúk) állnak a PHc-től – további végtermék-fejlesztést tehetnek lehetővé.

DOI: 10.15477/SZE.WAMDI.2019.003

ABBREVIATIONS AND ACRONYMS

Poultry genotypes used in the study

BHc	Bábolna Harco, egg type, mother line (study 6)
BRt	Bronze Turkey (study 1)
BTc	Black Transylvanian Naked Neck chicken (study 1)
COt	Copper Turkey (study 1)
FHg	Frizzled Hungarian Goose (study 1)
HLgf	Hungarian Landrace Guinea Fowl (study 1)
HUg	Hungarian Goose (study 1)
MIc	Vietnamese Mia chicken (study 5)
PHc	Partridge Coloured Hungarian chicken (study 1, 2, 3, 4, 5, 6)
SHc	Speckled Hungarian chicken (study 1, 2)
STc	Speckled Transylvanian Naked Neck chicken (study 1, 2)
THc	Bábolna Tetra H dual purpose, father line (study 6)
WHc	White Hungarian chicken (study 1, 2)
WHd	White Hungarian Duck (study 1)
WId	Wild Coloured Hungarian Duck (study 1)
WTc	White Transylvanian Naked Neck chicken (study 1, 2, 4)
YHc	Yellow Hungarian chicken (study 1, 2)

Offspring of poultry genotypes used in crossing studies

♀ BHc	Female offspring of Bábolna Harco, egg type, mother line (study 6)
♀ BHc x PHc	Female offspring of the cross: ♂ Bábolna Harco, egg type, mother line x ♀ Partridge Coloured Hungarian chicken (study 6)

DOI: 10.15477/SZE.WAMDI.2019.003

♀ PHc	Female offspring of Partridge Coloured Hungarian chicken (study 3, 4, 6)
♀ PHc x BHc	Female offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ Bábolna Harco, egg type, mother line (study 6)
♀ PHc x THc	Female offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ Bábolna Tetra H dual purpose (study 6)
♀ PHc x WTc	Female offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ White Transylvanian Naked Neck chicken (study 4)
♀ THc	Female offspring of Bábolna Tetra H dual purpose, father line (study 6)
♀ THc x PHc	Female offspring of the cross: ♂ Bábolna Tetra H dual purpose, father line x ♀ Partridge Coloured Hungarian chicken (study 6)
♀ WTc	Female offspring of White Transylvanian Naked Neck chicken (study 4)
♀ WTc x PHc	Female offspring of the cross: ♂ White Transylvanian Naked Neck chicken x ♀ Partridge Coloured Hungarian chicken (study 4)
♂ BHc	Male offspring of Bábolna Harco, egg type, mother line (study 6)

♂ BHc x PHc	Male offspring Bábolna Harco, egg type, mother line x ♀ Partridge Coloured Hungarian chicken (study 6)
♂ PHc	Male offspring of Partridge Coloured Hungarian chicken (study 4, 5, 6)
♂ PHc x BHc	Male offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ Bábolna Harco, egg type, mother line (study 6)
♂ PHc x THc	Male offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ Bábolna Tetra H dual purpose (study 6)
♂ PHc x WTc	Male offspring of the cross: ♂ Partridge Coloured Hungarian chicken x ♀ White Transylvanian Naked Neck chicken (study 4)
♂ THc	Male offspring of Bábolna Tetra H dual purpose, father line
♂ THc x PHc	Male offspring of the cross: ♂ Bábolna Tetra H dual purpose, father line x ♀ Partridge Coloured Hungarian chicken (study 6)
♂ WTc	Male offspring of White Transylvanian Naked Neck chicken (study 4)

♂ WTc x PHc	Male offspring of the cross: ♂ White Transylvanian Naked Neck chicken x ♀ Partridge Coloured Hungarian chicken (study 4)

Offspring of poultry genotypes used in keeping system comparing study

cf MIc x PHc	Offspring of the cross: ♂ Vietnamese Mia chicken x ♀ Partridge Coloured Hungarian chicken reared in complete free-range system in Vietnam (study 5)
sf MIc x PHc	Offspring of the cross: ♂ Vietnamese Mia chicken x ♀ Partridge Coloured Hungarian chicken reared in semi free-range system in Vietnam (study 5)
si MIc x PHc	Offspring of the cross: ♂ Vietnamese Mia chicken x ♀ Partridge Coloured Hungarian chicken reared in semi intensive system in Vietnam (study 5)
si MIc	Offspring of Vietnamese Mia chicken reared in semi intensive system in Vietnam (study 5)
si PHc	Offspring of Partridge Coloured Hungarian chicken reared in semi intensive system in Vietnam (study 5)

Studied parameters

ΔE	Total colour change (study 6)
ΔF	Inbreeding rate (study 1)
a*	Redness (study 6)
b*	Yellowness (study 6)

DOI: 10.15477/SZE.WAMDI.2019.003

BW	Body weight (study 3, 4, 5, 6)
Bw	Weight of deboned breast meat (study 3, 4, 6)
cFCR	Corrected feed conversion ratio (study 3)
Ci	Colour index (study 6)
Cw	Weights of eviscerated carcass (study 3, 4, 6)
EAw	Egg albumen weight (study 3, 6)
ELe	Egg length (study 3, 6)
Em	Egg mass (study 6)
EP	Egg production (study 2, 3, 6)
ESi	Egg shape index (study 3, 6)
ESs	Egg shell strength (study 6)
ESt	Egg shell thickness (study 6)
ESw	Egg shell weight (study 6)
Ew	Egg weight (study 3, 6)
EWi	Egg width (study 3, 6)
EYw	Egg yolk weight (study 3, 6)
FCR	Feed conversion ratio (study 3, 4, 5, 6)
H	Heterosis (study 4, 5, 6)
L*	Lightness (study 6)
Live%	Liveability (study 2, 3, 4, 5, 6)
n	Number of breeding flocks (study 1)
N_e	Effective population size (study 1)
N_f	Number of breeding females (study 1)
N_m	Number of breeding males (study 1)
RE	Reciprocal effect (study 4, 5, 6)
Tw	Weight of deboned thigh meat (study 3, 4, 6)

DOI: 10.15477/SZE.WAMDI.2019.003

Others

HáGK	Research Centre for Farm Animals Gene Conservation
HU	Hungary
MGE	Association for Hungarian Farm Animal Gene Conservation
POREC	Thuy Phuong Poultry Research Centre
VN	Vietnam

DOI: 10.15477/SZE.WAMDI.2019.003

1. INTRODUCTION

Data obtained from the State of the World's Animal Genetic Resources and Domestic Animal Diversity Information System global databank shows that indigenous or local breeds make up most of the world's poultry genetic diversity (FAO, 2015). According to TIXIER-BOICHARD et al. (2009) gene flow still takes place within local poultry population, which may result in both positive (maintain local poultry genetic diversity) and negative consequences (replace the local breeds with hybrids which may have lost some adaptive features). Among poultry species, chickens probably have the greatest variability. Indigenous chickens play important role in rural economies in most of the developing and underdeveloped countries (PADHI, 2016; OSWIN and KALISTA, 2017). However, in Europe, over the last decades, old, locally adapted chicken breeds are suffering dramatic decrease in numbers (GEERLINGS et al., 2002; GANDINI and VILLA, 2003). Only a small proportion of these breeds was used for the development of commercial strains (SPALONA et al., 2007). Producers interested in special poultry production using native chicken genotypes face several challenges. One challenge is that limited published data exist regarding their production parameters. The other is how to effectively and safely include them in practical use while preserving their unique productivity characters. Thus, conservation programmes focusing on disseminating the knowledge on their merit and maximizing the effective number of individuals is essential.

In Hungary, 7 native chicken breeds, including the Partridge Coloured Hungarian chicken (PHc), are officially registered by the Hungarian breeding authority and conserved under the Association for Hungarian Farm Animal Gene Conservation (MGE). Most of these stocks are kept by

DOI: 10.15477/SZE.WAMDI.2019.003

Hungarian academic institutions as *in vivo* gene banks (KOVÁCSNÉ GAÁL et al., 2002; SZALAY et al., 2009). Involving Hungarian indigenous poultry breeds in sustainable agricultural production is highly recommended by many scientists (KOVÁCSNÉ GAÁL et al., 2004; HODGES, 2006; BODÓ and SZALAY, 2007; SZALAY and KOVÁCSNÉ GAÁL, 2008). As gene bank or conservation stocks cannot be the subject of any kind of direct selection for certain production traits, many attempts to cross local breeds with either commercial (e.g. KOVÁCSNÉ GAÁL and KONRÁD, 2006; SIWENDU et al., 2013) or selected but still robust exotic breeds (GUÉYE, 1998) have been reported. By crossing, breeders can take advantage of interactions between genes to exploit genetic variation of each breed (VAN TIJEN, 1977). More importantly, the phenotypic markers of indigenous breeds that are advantageous for marketing of final products may appear through crossing. As a consequence, the present dissertation, based on the related scientific publications of the author (1) analyses the current status of 14 local Hungarian poultry breeds' populations; (2) investigates the adaptation and conservation potential of PHc in the subtropics; (3) examines the performance of crossbreds of PHc and other chicken breeds (commercial lines, old chickens of either nearby or distant origin); (4) identifies the heterosis in the crosses of PHc and other chicken breeds; and (5) determines the quality characteristics of PHc crossbreds that may be valued by modern consumers in terms of overall acceptability.

The dissertation is prepared based on the following published/going to be published original research/review papers:

- Lan Phuong, T.N., Dong Xuan, K.D.T. and Szalay, I. (2015) Traditions and local use of native Vietnamese chicken breeds in sustainable rural farming. World's Poultry Science Journal, 71(02), 385-396. (subchapter **2.4**)

- Szalay, I.T., Lan Phuong, T.N., Barta, I., Kovács, J.N., Dong Xuan, K.D.T., Bódi, L., Mihók, S., Benk, A. and Kovácsné Gaál, K. (2016) Evaluating the trends of population data, effective population size and inbreeding rate as conservation indices of old Hungarian poultry breeds between 2000 and 2015. European Poultry Science, 80, Paper 10.1399/eps.2016.132. 14 p. *(subchapter **3.1**, **5.1** and **6.1**)*
- Lan Phuong, T.N., Barta, I., Bódi, L., Dong Xuan, K.D.T., Kovács, J.N. Ferencz, T.R. and Szalay, I.T. (2014) Egg production profiles of seven traditional Hungarian chicken breeds. Archiv für Geflügelkunde, 78, Paper 10.1399/eps.2014.69. 9 p. *(subchapter **3.2**, **5.2** and **6.2**)*
- Dong Xuan, K.D.T., Lan Phuong, T.N., Tien, P.D., Thu, P.T.M., Khiem, N.Q., Nhung, D.T., Muoi, N.T., Oanh, N.T.K., Thanh, P.T.K. and Szalay, I.T. (2017) In situ and ex situ assessment of a native Hungarian chicken breed for its potential conservation and adaptation in the subtropics. Animal Production Science, 57 (5), 975-980. (*subchapter **3.3**, **5.3** and **6.3***)
- Szalay, I.T., Lan Phuong, T.N., Barta, I., Bódi, L., Emődi, A., Szentes, K.A. and Dong Xuan, K.D.T. (2017) Conservation aspects of meat producing ability and heterosis in crosses of two natively different local Hungarian chicken breeds. International Journal of Poultry Science, 15 (11), 442-447. *(subchapter **3.4, 5.4** and **6.4**)*
- Productivity studies and crossbreeding of two geographically distant native chicken breeds for enhanced conservation *(subchapter **3.5**, **5.5** and **6.5**; the paper is under preparation*)

DOI: 10.15477/SZE.WAMDI.2019.003

- Crossing as a safe and effective way to utilise indigenous Hungarian chicken genetic resources (*subchapter 3.6, 5.6 and 6.6; the paper is under preparation*)

2. LITERATURE REVIEW

2.1. Hungarian indigenous poultry genetic resources and their potential use in practice

Information on the origin and history of poultry genetic resources is highly required to the design of strategies for their sustainable management. In addition to 80 regional and 160 international transboundary avian breeds, there are 2303 local poultry breeds reported in the Domestic Animal Diversity Information System (DAD-IS) in 2014. Among avian species, local chickens have the highest number of breeds at risk and the regions with the highest proportion of breeds classified as at risk are Europe and the Caucasus (FAO, 2015). Although their productivity is low, they have not been replaced by commercial genotypes in rural areas due to various reasons. For example, most indigenous genotypes have strong mothering instincts and can hatch their own eggs without recourse to artificial incubation. They show heat-tolerant ability and are more resistant to bacterial and protozoan diseases and parasitic infestations than commercial broilers or layers. The indigenous birds can survive well under free-range or on scavenging and usually considered as a secondary occupation to other agricultural activities in households. Thus, they fulfil significant functions in the livelihood of rural smallholders (ABDELQADER et al., 2007). In many countries, they contribute significantly to total production and consumption of poultry meat (PYM et al., 2006). Their meat and eggs are generally preferred to those from commercial broilers and layers. Not only rural but also urban dwellers would pay a premium for these products (PYM, 2010).

Major historic events of Hungarian poultry conservations programmes are shown in Table 1. After approximately 40 years of execution, the total

DOI: 10.15477/SZE.WAMDI.2019.003

number of old Hungarian poultry breeds has been increased up to 14 (Table 2), mainly due to the registration of colour varieties as separate breeds and the gene rescue programmes. A new conservation stocks were established using pedigreed offspring of original, institutional and closed populations.

Table 1: Major historic events of Hungarian poultry conservations programmes

Year	Events
1897	The Hungarian Royal Poultry Breeding Farm (HRPBF, predecessor of HáGK) was founded.
Early 1930s	Major breeding program of old Hungarian poultry breeds started at HRPBF.
1939-1945	Most of breeding stocks were destroyed by World War II.
Early 1950s	Hungarian poultry breeds were preserved and propagated again in great quantities thanks to Balint Báldy and colleagues (BISZKUP and BEKE, 1951; BÁLDY, 1954).
Early 1960s	Hungarian breeds were replaced by foreign hybrids even in small-scale farms.
Early 1970s	Conservation of local chicken breeds became the task of the Hungarian Animal Breeding Authority to maintain Hungarian and Transylvanian breeds as gene reserves.
Early 1990s	Non-governmental organizations took over breed protection programmes according to new regulations in animal breeding.
	New poultry conservation programmes were initiated based on the existing breeding stocks of the Institute for Small Animal Research (KÁTKI, predecessor of HáGK) and three other agricultural universities in Mosonmagyarovar, Debrecen and Hodmezovasarhely (SZALAY, 2002; KOVÁCSNE GAÁL, 2004; MIHÓK, 2004, SÓFALVY, 2005; BENK, 2011; SZALAY, 2015).
In 1998	MGE was appointed as the official breeding organisation for old Hungarian poultry breeds and responsible for registering as well as supervising the whole breeding programme of the existing old Hungarian poultry stocks.
In 2008	Official registration to the Hungarian Poultry Information System of all poultry breeding stocks, including those kept under conservation programmes and those kept under the control of the breeding authority.
From 2010	Special EU subsidy system was elaborated and introduced for all officially registered Hungarian farm animal genetic resources, including poultry.
	Institutional and individual breeders have been encouraged to take part in the conservation programme for either research or production purposes.
From 2012	New gene rescue programmes to collect and conserve old local poultry breeds and ecotypes of the Carpathian Basin have been initiated by KÁTKI.
In 2013	Change the name of KÁTKI for HáGK.

DOI: 10.15477/SZE.WAMDI.2019.003

Old Hungarian chicken breeds belong to the medium size, dual-purpose category. Hens weigh 2.0 to 2.3 kg, while cocks weigh 2.5 to 3.0 kg. The highest value of Hungarian chicken breeds is their fine-fibred, excellent and palatable meat. Pullets at the age of 8 to 10 weeks are ready for marketing.

Table 2: List of conserved Hungarian poultry breeds registered in conservation programme (SZALAY, 2015)

Breeds	Labels
Yellow Hungarian chicken	YHc
White Hungarian chicken	WHc
Speckled Hungarian chicken	SHc
Partridge Coloured Hungarian chicken	PHc
White Transylvanian Naked Neck chicken	WTc
Black Transylvanian Naked Neck chicken	BTc
Speckled Transylvanian Naked Neck chicken	STc
Hungarian Landrace Guinea Fowl	HLgf
Frizzled Hungarian Goose	FHg
Hungarian Goose	HUg
White Hungarian Duck	WHd
Wild Coloured Hungarian Duck	WId
Copper Turkey	COt
Bronze Turkey	BRt

Their laying capacity reaches 140 to 150 eggs per hen per year. White, yellow, speckled and partridge colour are the most common ones. Transylvanian naked neck chickens are characterised by featherless neck, part of the breast and the belly. There is only a little plumage on the top of the head. These breeds are extraordinarily hardy, firm and resistant, and are acknowledged for their good winter laying characteristics. According to WINKLER (1921) and BAKOSS (1931), the progenitors of these birds were brought into the Carpathian Basin from Asia by the Hungarian conquerors at the end of the 9th century. The recent forms of Hungarian

DOI: 10.15477/SZE.WAMDI.2019.003

chickens must be the results of crossing between "ancient Hungarian" chicken with other breeds such as oriental or Mediterranean types. Over centuries of adaptation to continental climatic condition, these breeds have become very precious local varieties in the Carpathian Basin.

(a) (b)

Figure 1. Appearance of male (a) and female (b) Partridge Coloured Hungarian chicken

PHc was registered as the 7th old Hungarian chicken breed by KÁTKI (predecessor of HáGK) in 2004, as the result of a gene rescue programme. PHc has yellow or brownish-spotted beak, orange-red eyes with blood-red comb, face, earlobe and wattle. Its shank and toes are ivory white or yellow. The basic colour of female's plumage is brownish with partridge coloured patterns. The male PHc's plumage is very different from the female's due to sexual dimorphism. Its neck feathers, upper parts and primaries of wings are usually golden yellow. Its head is orange-red. The surface colour of breast, belly and thighs, middle part of wings and the main feathers of the tail are black with steel shade (Figure 1).

2.2. *Ex situ* conservation of live Hungarian poultry genetic resources

Most conservation programmes in developed countries are based on collaborations between *in vitro*, *in situ* conservation and animal breeding industry (FAO, 2007a). Nevertheless, only *in vitro* and *in situ* preservation are not enough to ensure genetic recovery. If breeds are geographically isolated, they may be at risk of being totally lost in localised catastrophes (CARSON et al., 2009). For this reason, it is also necessary to build some *ex situ* preserved live breeding stocks. The *ex situ* conservation of live population is captive breeding of indigenous poultry outside their natural environment (FAO, 2015). Through live conservation, breeds can be properly accessed, monitored and used in the present changing agroeconomic climate as well as available for future breeding strategy. Before creating an *ex situ* conserved live population, clear objectives must be defined with respect to whether the programme is to conserve unique genes within the population or the breed itself, whether conserved animals can adapt to new habitat and whether the conserved live population may cause any negative effect on local biodiversity existing in the designated new habitat. The size of founder flock is also very important. The larger the founder flock, the greater the range of genetic variation that will be incorporated into the conservation programme. The founder flock may later act as a nucleus which will interact with other farms or herds within the programme.

Recommended steps for establishing a live poultry ex situ gene conservation programme can be summarised as follows:

DOI: 10.15477/SZE.WAMDI.2019.003

1. Search for suitable habitat and partners.
2. Investigate the chosen habitat and its local biodiversity where intended to develop a live poultry ex situ conserved population.
3. Begin with an adequately sized nucleus flocks who should be noninbred and fertile. They should represent the range of genetic types found within the population.
4. Conduct adaptation study of conserved population in the chosen habitat.
5. Expand the population to a minimum effective population size and ensure the representation of the founder flocks in each generation.
6. Maintain the integrity of nucleus flocks and involve the full utilization of a breed in local practice.

Research into the real production characteristics of the breed can result in a renewed interest in the breed. More importantly, a new role of conserved breeds can be identified a in their new habitat as well as a regenerated home market of a locally adapted breed can be developed following the characterisation and evaluation process. Guinea fowl which are now numerous outside the continent of Africa is a good example in this case (ROMANOV et al., 1996; BAEZA et al., 2010; DONG XUAN et al., 2014; SZALAY et al., 2015).

2.3. Southeast Asia (SEA) – a potential region for *ex situ* poultry gene conservation

SEA contains about 10 percent of the world's agricultural population and about 4 percent of the world's total land area (FAO, 2007b). The countries of the SEA are diverse in terms of their population, land mass, GDP per capita, government systems and religion but uniform in term of rich biodiversity and affluent poultry genetic resource. According to ALDERS and PYM (2009), domesticated birds may have been introduced to other continents from SEA. Three percent of turkey breeds, 5 percent of chicken and goose breeds and 14 percent of duck breeds in the world are found in SEA. Out of 163 indigenous poultry breeds reported in the region, 2 breeds are under critical/critical-maintained category and 6 breeds are endangered while the status of the other 90 breeds are unknown (FAO, 2007b). However, these recorded data are probably an underestimate of the actual situation, primarily due to a lack of information. On one hand, most of SEA countries have a tropical climate. Monsoons influence the climate, which is characterized by hot temperatures, high humidity and rainfall in all months. Such a tropical climate may be favourable for poultry production in comparison with continental climate (e.g. climate in Hungary). On the other hand, poultry is one of the major animal protein resources in SEA due to the lowest production cost, income, price, lifestyle, population, trade and communication. At the same time, the region has also been considered as one of the largest potentials for livestock development in the world (TANGENDJAJA, 2010). Although most of poultry livestock produced in SEA comes from the industrial type of farming, small-scale and family poultry farming also exist in parallel and have been an integral part of regional poultry production for centuries (WILSON, 2007; BETT et al., 2014). This coexisting may continue to be for the foreseeable future. Thus, indigenous poultry breeds have higher chance to involve in. Likewise, the recent Asian economic crisis has caused some countries in SEA to reconsider the use of traditional breeds or at least in conjunction with commercial breeds (FAO/UNEP, 2000).

More and more governments and institutions have initiated policies and conservation programmes as well as invested on researches that help to improve the appreciation of indigenous genetic resources despite limited financial support, (e.g. FAO, 2003a; FAO, 2003b; FAO, 2003c; FAO, 2004). With above mentioned encouraging conditions, SEA would be a promising choice for *ex situ* poultry gene conservation.

2.4. Native Vietnamese chicken breeds (e.g. Mia chicken) and their traditional use in sustainable rural farming

Vietnam, a country located in Southeast Asia, has a small total land use area of approximately 33095 thousand ha, of which, approximately 10151 thousand ha is used for the agricultural production including crop land and animal raising land (GSO, 2013). With a subtropical monsoon climate, abundant water resource and regular long day lengths, Vietnam has favourable conditions for agricultural development including poultry production. Vietnam is listed among the countries, where multiple domestication events of the Red Jungle Fowl may have taken place more than 7000 years ago (ELTANANY and DISTL, 2010). Many statues of chickens in Vietnam, from the Early Bronze Age and the Early Stone Age, discovered by archaeologists show the importance of chickens in Vietnamese civilisation (VO, 1978; HIGHAM et al., 2011). Poultry rearing in Vietnam was reported to have started in the Tam Dao valley and the mountain of Ba Vi, which currently belongs to Vinh Phuc and Ha Noi provinces (DUC and LONG, 2008). According to the perception of Vietnamese people, local poultry farming is not easily replaced by others since it requires low investment, has short production cycle, and high marketing value. Gradually, poultry production became a traditional occupation in Vietnam. In 2013, the General Statistic Office of Vietnam reported that the poultry meat production in 2012 yielded 724.9 thousand tons and was ranked the second largest after pork. In addition, egg production in 2012 reached 7299 million pieces (GSO, 2013).

Traditional extensive backyard poultry production system, classified by FAO in 2004, which is defined as “village farming system” by the Vietnamese Ministry of Agriculture and Rural Development in 2006 was by far the most common production system across the country (BURGOS et al., 2007). This system is practised by 84-85% of rural families in the Northeast-Northwest of Vietnam and between 42-71% of those in the Southeast-Mekong River Delta regions (EPPRECHT and ROBINSON, 2007). The system is continuous and considered to be small scale with flock size less than 50 birds. Farmers are taking birds out of flocks either for self-consumption or for sale to nearby markets and urban areas through informal channels, while simultaneously introducing new ones (IFFT and ZILBERMAN, 2012). However, farmers hardly know exactly how many birds they own and rarely document. Their knowledge to rear chicken in this system is often passed from generation to generation (DUC and LONG, 2008). Rural families living in South Vietnam tend to keep more chickens in an intensive and market-oriented production system with higher inputs (EPPRECHT and ROBINSON, 2007).

BURGOS et al. (2007) proposed to divide this kind of system into two categories, the semi-intensive commercial poultry production system and the intensive industrial poultry production system. In this case, birds are selected to grow fast in small spaces and under a diet of concentrate feed. Some of final products are sold in traditional markets, but much of it is sold in supermarkets or to food companies. Mixed farming systems, such

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as a garden-fish pond-chicken cages system (VIET LY, 2004) or an integrated crop-chicken production system (DEVENDRA, 2007), are also common in the rural areas. Adopting the breed definition of FAO in 2007, Vietnamese researchers detected more than 30 native chicken breeds. Place of origin and the endangered status of these chicken breeds are listed in Table 3. The terms “normal”, “vulnerable” and “extinct” are used according to FAO definitions. These breeds are popular in either village farming or mixed farming systems.

They vary in size, generally exhibit low performance (MINH et al., 2006; DUC and LONG, 2008), but require few inputs and are known for being able to handle a free-range environment (IFFT and ZILBERMAN, 2012). VIET LY (1998) reported that local Vietnamese chicken breeds made up more than 80% of the chicken population in the whole country and in 2007, local Vietnamese chicken populations still accounted for more than 70% of the country’s total number of chickens (HONG HANH et al., 2007). It is in accordance with the data of TIEU et al. (2008), who also reported that 75% of eggs are produced by local chicken breeds. Although the population of imported exotic chicken breeds and crossbreeds between local and imported ones with higher productivity (VANG et al., 2001; COI et al., 2006; NGA et al., 2006) increases year by year, the local Vietnamese chickens seem to remain popular and keep a wide diffusion role in achieving various goals of individual smallholders living in underdeveloped and underprivileged regions.

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Table 3: List of Vietnamese native chicken breeds with the origin and level of use (VANG, 2003; SU et al., 2004; TIEU et al., 2008; TIEU, 2009)

Breed	Origin	Level of use
Ac	Vinh Long	H
Banhlai Damprong	Gia Lai	L
Choi	Binh Dinh	H
Cup	Lam Dong	L
Dong Tao	Hung Yen	L
Dwarf chicken	Yen Bai	-
Feather leg chicken	Ha Giang	L
GF chicken	Ha tay	L
GT chicken	Ha Tay	L
Hac Phong	Quang Ninh	H
Hmong Black	Son La	H
Hmong Brown	Son La	H
Hmong White	Son La	H
Ho	Bac Ninh	L
Hre	Quang Ngai	H
Lien Minh	Cat Ba	-
Man	Quang Ninh	H
Man Dien Bien	Dien Bien	L
Mia	Son Tay	H
Mong	Ha Nam	-
Oke	Ha Giang	H
Phu lu Te	Ha Tay	-
Ri	North Vietnam	H
Sao Trang	Long An	L
Sao Vang	Long An	H
Six toes chicken	Lang Son	L
Smooth feather chicken	Ha Giang	L
Tau Vang	South Vietnam	H
Te Dong Bac	Lang Son	L
Te/Lun	Ha Giang	H
Tien Yen	Quang Ninh	H
To	Thai Binh	H
Tre	-	H
Troi	Quang Ninh	H
Van Phu	Yen Bai	Extinct
Vu Quang	Ha Tinh	L
Xuoc	Ha Giang	L

L: low; H: high; -: no information

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Poultry rearing, and poultry consumption are linked to socio-cultural factors (AKLILU et al., 2008; WILSON, 2010). Particularly in Vietnamese agriculture, chicken is a vestige of civilisation and culture. Various local chicken breeds have appeared in Vietnamese poetry and folk paintings with the meaning of peace and prosperity. For hundreds of years, local chickens have been given as a gift for maintaining relationships that are not economic in nature, but rather based on exchange and reciprocity, which reinforces the social bond within the family and community.

According to the Vietnamese historians, the peasants used to offer the specially raised Mia chickens (Duong Lam village), Ho chickens (Dong Ho village) and Dong Tao chickens (Hung Yen) to the King. They also give away a live backyard chicken to relatives and neighbours as a gesture to thank them for helping with agricultural work or as a special present to sick people. Meanwhile, the local chickens are also consumed as part of ritual and secular celebration. They are sacrificed for honouring the ancestors, for worshiping heaven and earth, for exchange related to marriage. Some traditional ceremonies of Vietnamese in the northern regions require a chicken with particular colour, such as Ri chicken with yellow skin (MOULA et al., 2011). Chickens that satisfy these unique requirements are the most conveniently found at the local market.

In addition, the local chickens obviously illustrate the rich human-animal relationship. Chicken ownership can be a measure of social status, competence and prestige of farmers in the rural area. Choi chicken is a classic sample. This chicken is raised to target traditional cock fighting events, held annually. Choi is selected for its strong shank with sharp heel. The performance of these cocks provides not only social entertainment, but also represents the owner’s honour and strength.

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Furthermore, the importance of keeping backyard chickens for Vietnamese women has been reported in several articles (CUC et al., 2006; BURGOS et al., 2007). Backyard chickens are generally accepted as one of the "women's capital". Vietnamese women act as a day-to-day manager of backyard chickens with help from their children and family elders. Vietnamese women are the ones who feed the chickens, clean the coops and apply veterinary treatments (TUNG, 2005). On one hand, keeping backyard chicken is a suitable income-generating activity that Vietnamese women can carry parallel with other domestic duties. On the other hand, it requires low investment and generates quick returns, which fits well in the picture of women's day-to-day expenditure as a household caretaker. Consequently, chicken offer the Vietnamese women a chance to earn respect for their contribution as a family labour as well as create an at-home job for the elderly.

The backyard chickens keeping system takes advantages of not only family labour, but also feed resources which have no or only alternative value. The basis of backyard chicken feeding is rice (cooked grains, meal or bran), maize, cassava, aquatic plant (*Ipomoea aquatica*), and kitchen residues. The amount of feed taken depends heavily on the need of chickens and availability of grains that the owners have in their storage. Chick replacement is generally hatched from the farmer's own stock eggs and rarely purchased from the local market. These facts result in low input and low labour requirement, a very characteristic feature of backyard chicken keeping.

According to the perception of Vietnamese famers, backyard chicken farming has a short production cycle and high marketability with low exclusion risk (HONG HANH et al., 2007). The low exclusion risk means that the Vietnamese local chicken breeds are not easily replaced by other farm animals. The farmers can utilise the backyard chickens as a cheap, but high-quality source of protein for home consumption. Meanwhile, they can gain some amount of cash income by selling various backyard chicken products such as meat, egg, viscera, feather and even chicken manure, at different stages of production throughout the year easily to traders, to other farmers in the vicinity. Thus, backyard chickens can be considered as a form of saving. Although this form of saving is small and limited, it can be converted into cash rapidly and efficiently with relatively low transaction costs (GUÉYE, 2005). It contributes about 35% of the household’s income originating from animal husbandry (CUONG, 2010) and can reach more than 30% of the total household income (BURGOS et al., 2007). This contribution is essential for the households living below the poverty level in rural areas, this contribution is essential. In the poorest Vietnamese households, a few backyard chickens may be the only asset that they can use to cover some immediate but small expense. The lower the income group, the higher and more important the average contribution to income made by poultry (EPPRECHT, 2005).

Definitions and concepts of sustainable agriculture cited by KEENEY (2013), which is resting on the principle to meet the needs of the present without compromising the ability of future generations to meet their own needs, is also valid for poultry production. According to multicriteria approach, suggested by CASTELLINI et al. (2012), in which they combined social, cultural and economic indicators into the many dimensions of sustainability to evaluate better sustainable farming systems, all the characters of local Vietnamese chicken breeds seem to fit well into the framework of sustainable agriculture. However, the relevant questions are, how to reach equilibrium between social, cultural and economic performance of these breeds and how to integrate them efficiently into sustainable farming along with the rapidly changing domestic poultry industry. From this point of view, it is essential to start with different strategies specifically designed for the extensive keeping system using improved old chicken breeds that maintain adaptability to the natural environment while simultaneously having acceptable productive efficiency. SZALAY et al. (2003) once suggested that the utilisation of local chicken genetic resources in sustainable rural development can be considered at three levels: (1) high quality product and natural production-oriented farming; (2) ecology-oriented farming; (3) agro-environment oriented use of local breeds. And, the conservationists believed that the lower performance of local breeds can be compensated by their special quality and cultural importance.

The evolution and formation of local breeds is the result of natural adaptation process of animals to the local natural and human environment, which is the basis of their sustainable existence in the present agricultural practice. On contrary, the commercial breeds adapted in intensive/semi-intensive keeping system, are mainly imported from abroad, and selected for production within a narrow frame of artificial and uniform environment, where disease resistance and tolerance can be overcome by application of appropriate technologies.

On one hand, they cannot be used efficiently and sustainably in natural condition (STEINFELD et al., 1997). On the other hand, both over-selection and "artificial" environment is leading industrial production towards the "safe and free of everything" status, and at the same time changes to the traditional taste of chicken products (SZALAY and DONG

XUAN, 2007). This might be the reason why domestic markets still place a premium on special traditional chicken varieties compared to the industrial ones. In urban or suburban regions, where both income and the consumption of animal protein is increasing as markets have become saturated, people tend to look for native chicken products with specific quality and they are willing to pay higher price for them than for industrial chickens. IFFT (2011) reported that a significant willingness to pay for free range chicken was approximately a 10-15% premium. If production thoroughly follows recognised protocol and is strictly controlled by the authorities, the final products can be certified as safe, high quality premium local products. Certification is the determining factor that improves the product’s market price as well as increases the scope for national chicken product and industrial diversification. The system may utilise pure local chicken breeds, which can be commercialised in a way that make consumers recognise their specific appearance and characteristics. As such, the low performance of these native chickens can be compensated by the higher price. Meanwhile, they can be involved in various regional developmental projects such as on-farm selling of local products, rural tourism. The other possibility is to elaborate crosses of indigenous breeds with intensive ones which produce well under natural conditions.

2.5. Utilisation of indigenous chicken genetic resources by crossing

Involving indigenous chicken in poultry related sustainable agricultural production is highly recommended by many scientists (HODGES, 2006; BODÓ and SZALAY, 2007; MTILENI et al., 2012). However, producers interested in special poultry production using native chicken genotypes face several challenges. One challenge is that little published data exists regarding their production parameters. The other is how to effectively and safely include them in practice while preserving their unique productivity characters. Many attempts to cross local breeds with either commercial ones or selected but still robust exotic breeds (e.g. OMEJE and NWOSU, 1988; BEKELE et al., 2010; SIWENDU et al., 2013; UDEH, 2015) have been reported.

In the study of OMEJE and NWOSU (1988), local Nigerian chicken breeds were crossed with Golden-link commercial chickens, and their crossbreds showed some appreciate productive traits. BEKELE et al. (2010) found that body and egg weight could be improved by crossing Netch cockerels (an Ethiopian local breed) and Fayoumi (exotic breeds). In the study of SIWENDU et al., (2013), heterosis could be seen, when crossing indigenous breed named Venda with another indigenous breed named Naked Neck or commercial broiler breed named Ross 308. In the study of UDEH (2015), significant improvement in the body weight and weight gain could be obtained, when an indigenous Nigerian breed was crossed with 2 exotic lines. By crossing, breeders can take advantage of interactions between genes to exploit genetic variation of each breed (VAN TIJEN, 1977; FAIRFULL, 1990; KITALYI, 1998). More importantly, the phenotypic markers of the indigenous breeds that are advantageous for marketing of final products may appear through crossing.

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3. MATERIALS AND METHODS

3.1. Population study of 14 indigenous Hungarian poultry breeds

The population data of entirely controlled stocks of 14 local Hungarian poultry breeds (Table 2), either officially registered with MGE or existing and temporarily unregistered, including YHc (in Gödöllő, Mosonmagyaróvár, Dejtár, Apajpuszta, Farmos and Napkor), WHc in (Gödöllő, Dejtár, Apajpuszta and Napkor), SHc (Gödöllő, Dejtár, Apajpuszta, Farmos, Napkor and Budapest), PHc (Gödöllő, Apajpuszta, Napkor and Budapest), WTc (Gödöllő, Dejtár, Apajpuszta and Napkor), BTc (Gödöllő, Dejtár, Apajpuszta and Napkor), STc (Gödöllő, Dejtár, Apajpuszta and Napkor), HLgf (Gödöllő, Apajpuszta, Napkor, Hortobágy, Tiszafüred and Budapest), FHg (Gödölő, Apajpuszta, Farmos, Napkor, Tiszafüred and Budapest), HUg (Gödöllő and Farmos), WHd (Gödöllő, Apajpuszta, Farmos and Budapest), WId (Gödöllő, Apajpuszta and Farmos), COt (Gödöllő, Apajpuszta and Napkor) and BRt (Gödöllő, Apajpuszta and Napkor) were considered for evaluation in this study. The data were collected consistently from 2000 to 2015 by MGE and HáGK. Yearly, the number of breeding stocks (n), the number of breeding males (N_m) and females (N_f) were monitored. Sex ratio (N_m/N_f) is defined as the N_m to the N_f in a population. The N_e is the number of individuals from a population that are randomly selected and randomly mated and would be expected to have the same rate of inbreeding (WAPLES, 2002). Since breeding birds were kept in various locations of Hungary, the assumptions of random mating and no selection are unrealistic. In this study, however, N_e was estimated only to provide the presumption of upper limit. ΔF within a population is inversely proportional to N_e. The estimation of N_e and ΔF was based on the formula given by WRIGHT (1931) as follows:

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$$N_e = \frac{4N_m N_f}{N_m + N_f} \quad (1)$$

$$\Delta F = \frac{1}{2N_e} \quad (2)$$

Where: N_f is the number of breeding females, N_m is the number of breeding males. The ratio of the effective population size to total population size (N_e/N) was also calculated to indicate the extent of genetic variation (FRANKHAM, 2007).

3.2. Egg production study of 7 indigenous Hungarian chicken breeds

Data were recorded from 7 native/old Hungarian chicken breeds (YHc, WHc, PHc, SHc, BTc, WTc and STc), which hatched from *in vivo* gene bank of HáGK. To determine the egg production profiles of these breeds, 2 different examinations were carried out. In the first examination, the whole set of egg production data obtained in the first laying period of two subsequent generations was studied. In the second one, the egg production of two subsequent laying periods (from January to June) were compared. All layers were kept under the same conditions with daytime access to open air and treated with the same diet. As all nucleus flocks were hatched in May, egg production of the flocks started in late autumn and proceeded until the middle of summer, which is the usual pattern for natural backyard poultry. Therefore, birds produced eggs in the wintertime too. Consequently, no lighting and heating regimes were applied throughout the egg production. The female to male ratio of each group was 7:1, recommended by MGE (SZALAY et al., 2009).

3.3. Adaptation study of Partridge Coloured Hungarian chicken in the subtropics

In this study, 500 PHc chicks were hatched from HáGK *in vivo* gene bank stock, while another 500 chicks of the same origin were hatched from eggs directly imported by Thuy Phuong Poultry Research Centre (POREC), Vietnam. The two experimental flocks were reared in parallel, one at the poultry farm of HáGK, Hungary (HU) and the other one at POREC, Vietnam (VN). Differences in some basic climatic parameters between Hungary (Budapest station) and Vietnam (Hanoi station) are shown in Table 4.

Table 4: Difference in climatic parameters (monthly average values) between North Vietnam (recorded at Hanoi station, according to General Statistic Office of Vietnam) and Hungary (recorded at Budapest station, according to Országos Meteorológiai Szolgálat of Hungary)

Trials	Months	Temperature ºC		Humidity %		Sunshine duration hours		Rainfall mm	
		VN	HU	VN	HU	VN	HU	VN	HU
Growing	May	27	16	76	61	138	234	149	62
	June	29	19	80	61	127	250	395	63
	July	30	21	77	59	151	271	254	45
Egg laying	November	25	5	76	78	104	67	31	53
	December	17	2	67	80	79	48	51	43
	January	18	0	81	79	40	62	80	37
	February	21	2	80	74	38	93	80	29
	March	22	6	78	66	55	137	50	30
	April	23	12	85	59	57	177	55	42
	May	29	17	81	61	138	234	149	62

Growth was monitored from May (hatching day) to July 2010 and egg production from November 2010 to May 2011. The same husbandry technology described by MGE was applied in both locations (MGE, 2009).

During the meat production trial, birds were allocated to 20 pens (10 pens at POREC and 10 pens at HáGK) with 50 birds/pen. Initially, birds were kept in closed cages (5 birds/m^2, concrete floor with 5-6 cm deep bedding made from shavings and 25 cm of perch space per bird). In the first 3 weeks of rearing, birds were fed with commercial mixed feed (starter type). Later, feedstuffs were changed to grains that were locally available and additional protein requirement was supplemented by soybean meal and processed infertile, broken or substandard eggs from the hatchery.

Although the types of feed and premix used for the VN and HU flocks were not identical, it was ensured that feed diet, calculated based on chemical feed composition (Table 5), was the same at both locations. From 4 weeks of age, birds were released in a running area of 4 m^2/bird during the day, which was closed at night. Lighting and prophylactic programmes are described in Table 6.

Table 5: Average chemical feed composition used for adaption study of Partridge Coloured Hungarian chicken calculated at the Research Centre for Farm Animal Gene Conservation in Hungary (HU) and at Thuy Phuong Poultry Research Centre in sub-tropical climatic zone of North Vietnam (VN).

Composition	Unit	1-3 wks of age	4-19 wks of age	20-22 wks of age	> 22 wks of age
Energy	MJ/kg	12.2	11.7	11.1	10.8
Dry matter	%	87.0	86.9	86.9	87.2
Crude protein	%	21.6	20.5	16.9	16.7
Fat	%	4.0	0.11	3.3	3.7
Fibre	%	3.5	4.0	4.1	4.2
Lysine	%	1.0	1.1	0.76	0.75
Methionine	%	0.42	0.40	0.33	0.32
Methionine + Cysteine	%	0.70	0.66	0.57	0.56
Threonine	%	0.82	0.79	0.62	0.61
Tryptophan	%	0.24	0.24	0.19	0.18
Arginine	%	0.11	0.09	0.15	0.10
Isoleucine	%	0.08	0.06	0.10	0.07
Leucine	%	0.16	0.12	0.21	0.15
Valine	%	0.11	0.08	0.14	0.10
Ca	%	0.92	1.0	2.7	3.92
P	%	0.65	0.65	0.56	0.65
Na	%	0.12	0.12	0.13	0.13
Vitamin A	IU/kg	12000	12000	12000	12000
Vitamin D-3	IU/kg	4000	4000	4000	4000
Vitamin E	mg/kg	35.0	35.0	35.0	35.0

wks: weeks

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Table 6: Lighting and prophylactic programs used for adaption study of Partridge Coloured Hungarian chicken reared in parallel at the Research Centre for Farm Animal Gene Conservation in Hungary (HU) and at Thuy Phuong Poultry Research Centre in sub-tropical climatic zone of North Vietnam (VN).

Age	Lighting duration (hours)	Irradiance (W/m^2)	Prophylactic measures
1 day	24	3	Vaccination against Marek disease
1 wk	23	3	
2 wks	21	2	1st vaccination against Gumboro disease
3 wks	19	2	1st vaccination against Newcastle disease and infectious bronchitis
4 wks	17	1	
5 wks	15	1	
6 wks	14	1	
7 wks	13	1	
8 wks	12	1	2nd vaccination against Newcastle disease and infectious bronchitis
9 wks	11	1	2nd vaccination against Gumboro disease
10 wks	10	1	
11wks	9	1	
12 wks	8	1	Vaccination against infectious avian encephalomyelitis
18 wks	8	1	Vaccination against Newcastle disease, bronchitis and Gumboro-Small pox

wks: weeks

All birds had free access to feed and clean water. Mortality, individual body weight of birds and feed intake of each pen were measured monthly (at 4, 8 and 12 weeks of age). At the end of the 12th week, experimental birds were sexed based on their appearance to define the sex ratio. While feed conversion ratio (FCR, kg feed ⁄ kg body weight gain) is calculated according to the number of live birds recorded monthly in each pen, corrected feed conversion ratio (cFCR, kg feed ⁄ kg body weight gain) is a predicted value when the number of males and females in a pen is equal.

$$\mathrm{FCR} = \frac{\text{Feed intake per pen (kg)}}{\text{Number of live birds} \times \text{Average body weight gain (kg)}} \quad (3)$$

$$\mathrm{cFCR}_{at\ sex\ ratio\ of\ 1} = \frac{\mathrm{FCR}}{\text{Recorded sex ratio}} \quad (4)$$

Following sexing, 10 males from each pen with average body weight (BW) were slaughtered to investigate the weights of eviscerated carcass (Cw), deboned breast meat (Bw) and thigh meat (Tw), the percentages of which were calculated as below:

$$\mathrm{Cw\%} = \frac{\mathrm{Cw\ (g)}}{\mathrm{BW\ (g)}} \quad (5)$$

$$\mathrm{Bw\%} = \frac{\mathrm{Bw\ (g)}}{\mathrm{BW\ (g)}} \quad (6)$$

$$\mathrm{Tw\%} = \frac{\mathrm{Tw\ (g)}}{\mathrm{BW\ (g)}} \quad (7)$$

At 20 weeks of age, 200 females and 20 males of both the HU and VN flocks were moved to four laying pens (50 females and 5 males per pen). The total number of intact eggs produced daily was recorded throughout the 1st laying period. To avoid disturbance, the body weight and feed intake of layers were not monitored. Eggs were collected twice a day. Egg production (EP) was calculated using the following formula:

$$\mathrm{EP} = \frac{\text{Number of eggs produced on a daily basis}}{\text{Number of birds available in the flock}} \times 100 \quad (8)$$

To measure egg weight (Ew), egg yolk (EYw), egg albumen (EAw) and egg shell (ESw) weight, as well as egg length (ELe) and egg width (EWi), 30 randomly selected eggs produced by 36-week-old layers were used. Egg shape index (ESi) was calculated as follows:

$$\mathrm{ESi} = \frac{\mathrm{EWi}}{\mathrm{ELe}} \quad (9)$$

The same incubating technology was used in both study stations. Fertile eggs and embryonic deaths were identified by egg candling on the 7^{th} day of incubation. Fertility as the percentage of fertile eggs, hatchability as the percentage of hatched eggs, number of substandard hatchlings and standard hatchlings were recorded. The research was approved by the local ethics committees of HáGK and POREC.

3.4. Crosses of Partridge Coloured Hungarian and a natively different Hungarian chicken breed

Chicks of four investigated genotypes (PHc and WTc purebreds and the offspring of reciprocal crosses ♂WTc x ♀PHc and ♂PHc x ♀WTc) were hatched at the poultry gene bank farm (HáGK), Hungary. Wing bands were used for individual recording. Appearance of WTc was shown in Figure 2.

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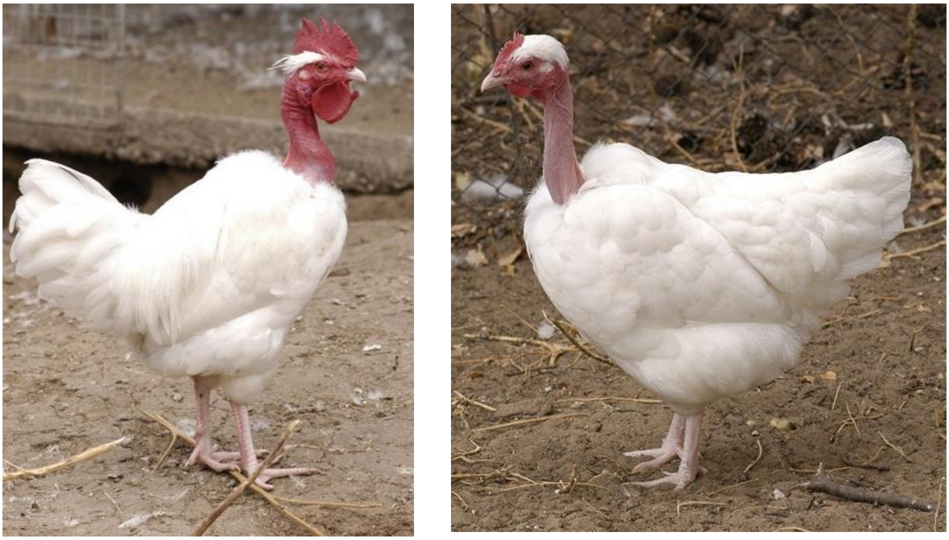

(a) (b)

Figure 2. Appearance of male (a) and female (b)
White Transylvanian Naked Neck chicken

Initially, the experimental groups of birds were kept separately in closed cages on deep litter. From 4 weeks of age, birds were released in a running area during the day and closed at night. Birds had free access to feed and water. The arrangement of the experiment and the labelling of experimental groups are described in Table 7. Liveability (Live%), individual BW of birds and feed intake of each pen were recorded during the experiment and calculated for 12, 14 and 16 weeks of age. FCR is calculated according to the number of live birds recorded in each pen, using the equation (3). To study slaughtering yield, individual live weight, eviscerated carcass, breast and thigh weight of 4 randomly chosen birds of each pen were measured at the age of 12, 14 and 16 weeks. Cw% was estimated by equation (5).

Table 7: Experimental arrangement of study 4: Crosses of PHc and a natively different Hungarian chicken breed (WTc)

Parents (♂ x ♀)	Gender	Number of pens	Number of birds per pen	Labels
PHc x PHc	male	3	20	♂ PHc
	female	3	20	♀ PHc
WTc x WTc	male	3	20	♂ WTc
	female	3	20	♀ WTc
PHc x WTc	male	3	20	♂ PHc x WTc
	female	3	20	♀ PHc x WTc
WTc x PHc	male	3	20	♂ WTc x PHc
	female	3	20	♀ WTc x PHc

PHc: Partridge Coloured Hungarian chicken; WTc: White Transylvanian Naked Neck chicken

Heterosis was calculated using means, with the formula adapted from WILLIAMS et al. (2002):

$$H\ (\%) = \frac{F1 - 0.5\ \times (P1 + P2)}{0.5\ \times (P1 + P2)} \times 100 \qquad (10)$$

where, H is heterosis in percentage of parental performance, F1 is the performance of crossbreds, P1 and P2 is the performance of the progeny from each of the two parental populations. RE for each parameter were calculated as the difference between reciprocal F1 performances with the formula adapted from SOLA-OJO et al. (2012):

$$RE = P1 - P2 \qquad (11)$$

3.5. Crosses of Partridge Coloured Hungarian and an old chicken breed of distant origin

Three experimental flocks (♂MIc x ♀MIc; ♂PHc x ♀PHc and ♂MIc x ♀PHc) were allocated in 6 pens (2 pens/flock, 3 males and 30

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females/pen), with natural mounting under natural photoperiod. The appearance of Vietnamese Mia chicken is shown in Figure 3.

(a) (b)

Figure 3. Appearance of male (a) and female (b) Vietnamese Mia chicken

Egg production was monitored between 23 and 68 weeks of age and eggs of 37 to 38-week old layers were collected for incubation. EP was calculated using the formula (8). Hatched chicks separated by genotype were labelled. 450 chicks (150 chicks allocated in 3 pens /genotype) were reared in semi intensive (si) keeping system at POREC. 480 crossbred chicks were transferred to family farms located in Yen Noi village, Vinh Phuc province of North Vietnam, in which, 240 birds were reared in 3 farms with semi free range (sf) keeping system and the other 240 in 3 farms with complete free range (cf) keeping system (80 chicks/farm). The semi free range and complete free-range keeping systems are shown in Figure 4.

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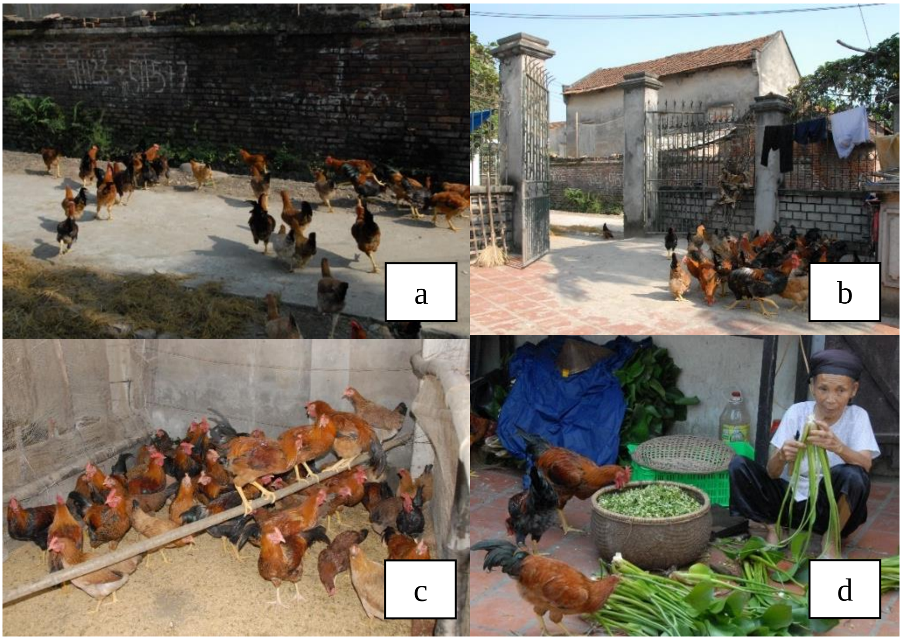

Figure 4. The semi free range (closed at night) and complete free range (not closed at night) keeping systems used in the study of cross between Partridge Coloured Hungarian chicken and Vietnamese Mia chicken
(a, b): running areas; (c): indoor area;
(d): chicken feeds made from local plants

In the first 4 weeks, all birds were kept in closed cages and fed with commercial mixed feed (starter type). From the age of 5 weeks, the keeping systems varied. In the si and sf systems, birds were housed as follows: 5 birds/m^2, concrete floor with 5-6cm deep bedding made from shavings and 25cm of perch/bird. They could go out during daytime and were closed at night. While the si system was designed to have a small fenced running area (5 birds/m^2), the sf included a large fenced foraging area (approximately 30m^2/bird). In cf system, birds could move freely all the time in a fenced yard with trees against direct sunlight (40-50m^2/bird, earth floor). The trial arrangement and labels of birds are shown in Table 8. While the birds at POREC were primarily aimed for genotype comparison in terms of growth performance and slaughter yield, the birds at family farms were kept for investigating the effect of keeping system on the growth performance of crossbreds. Birds had free access to the same feed and clean water. Body weight was recorded on hatching day, at the age of 4, 8 and 12 weeks. FCR was calculated and corrected according to formula (3) and (4). Cw, Bw and Tw (all with skin) as well as abdominal fat of 6-6 randomly slaughtered male and female birds kept in si system were measured at the end of a 12-week rearing period. Heterosis was calculated using equation (10).

Table 8. Experimental arrangement of study 5: Crosses of PHc and an old chicken breed of distant origin (MIc)

Parents (♂ x ♀)	Offspring label	Pens per farm	Birds per pen	Keeping systems applied	
				1-4 wks	5-12 wks
MIc x MIc	si MIc	3	50	Closed	Semi intensive $5m^2$ running area/bird*
PHc x PHc	si PHc	3	50	Closed	Semi intensive $5m^2$ running area/bird*
MIc x PHc	si MIc x PHc	3	50	Closed	Semi intensive $5m^2$ running area/bird*
MIc x PHc	sf MIc x PHc	3	80	Closed	Semi free range $30m^2$ running area/bird**
MIc x PHc	cf MIc x PHc	3	80	Closed	Complete free range up to $50m^2$ running area/bird**

*PHc: Partridge Coloured Hungarian chicken; MIc: Vietnamese Mia chicken chicken; *: reared in Thuy Phuong Poultry Research Centre; **: reared at family farms*

3.6. Crosses of Partridge Coloured Hungarian and 2 Bábolna Tetra's chicken lines

The study was conducted at the poultry farm HáGK. Seven parental flocks of the same age: ♂PHc x ♀PHc, ♂THc x ♀THc, ♂BHc x ♀BHc, ♂PHc x ♀THc, ♂PHc x ♀BHc, ♂THc x ♀PHc, ♂BHc x ♀PHc were established with sex ratio of 1 male to 7 females and natural mounting under natural photoperiod. PHc originated from the nucleus flock of HáGK gene bank. THc and BHc were provided by BÁBOLNA TETRA Ltd. THc is Bábolna Tetra H dual purpose, father line (BÁBOLNA TETRA Ltd., 2014) and BHc is Bábolna Harco egg type, mother line (BÁBOLNA TETRA Ltd., 2013). The appearance of THc and BHc is shown in Figures 5 and 6.

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(a) (b)

Figure 5. The appearance of Bábolna Tetra H dual purpose, father line male (a) and female (b)

(a) (b)

Figure 6. The appearance of Bábolna Harco egg type, mother line male (a) and female (b)

Egg of 34-week old layers were collected for incubation. Hatched chicks were sexed, labelled with wing bands and allocated in separated male and female poultry houses. The arrangement and labels of birds are shown in Table 9. Chicks of each genotype were distributed into 6 pens (12 birds/m^2, deep litter). Live%, weekly individual BW and feed consumption per pen was measured. FCR was calculated by equation (3). At the age of 12 weeks, all males were slaughtered, and females were reared further for egg production study.

Table 9: Experimental arrangement of study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Parents (♂ x ♀)	F1 labels		Number of:	
	male	female	pens per gender	birds per pen
THc x PHc	♂ THc x PHc	♀ THc x PHc	3	50
BHc x PHc	♂ BHc x PHc	♀ BHc x PHc	3	50
PHc x THc	♂ PHc x THc	♀ PHc x THc	3	50
PHc x BHc	♂ PHc x BHc	♀ PHc x BHc	3	50
PHc x PHc	♂ PHc	♀ PHc	3	50
THc x THc	♂ THc	♀ THc	3	50
BHc x BHc	♂ BHc	♀ BHc	3	50

PHc: Partridge Coloured Hungarian; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco, egg type, mother line

After slaughtering and cooling to the temperature of 4°C, Cw, Bw and Tw were investigated. Their percentages were calculated as described in formula (5), (6) and (7). During the first laying period, number of eggs laid on daily basis were recorded, and EP was calculated using the formula (8). At 28, 34 and 40 weeks of age, Ew, ELe, EWi, ESi, shell strength (ESs) and shell thickness (ESt) of 15 randomly selected eggs from each pen were evaluated. Ew was measured with an electronic balance to the nearest of 0.001g. The measurements of ELe and EWi were taken by a digital calliper to the nearest of 0.010mm. The ESi was determined using formula (9). ESt was measured at the sharp edge of eggs using micrometer. ESs was determined using “puncture” method described by VOISEY and HUNT (1974) and expressed in Newton (N).

Egg mass (Em) per layer in kg was calculated as following:

$$\mathrm{Em} = (\text{Number of eggs per layer x Ew})/1000 \qquad (12)$$

Breast meat colour at 3 and 24 hours after cutting as well as the shell colour of eggs from 28, 34 and 40-week old layers was determined on the surface using the L*a*b* system (Minolta® CR 410 Chromameter). L* (lightness) describes the relationship between reflected and absorbed light, without regard to specific wavelength and ranges from 0 (black) to 99 (white). Positive a* values are red and negative a* values are green (ranges from +60 to -60). Positive b* values are yellow and negative b* values are blue (ranges from +60 to -60). Higher L*, a* and b* values correspond to paler, redder and more yellow meat, respectively.

The colour index (Ci) was determined as following:

$$\mathrm{Ci} = \mathrm{L}^* - \mathrm{a}^* - \mathrm{b}^* \qquad (13)$$

Lower Ci values corresponded to a darker colour. The calculation of Ci is adapted from LUKANOV et al. (2015). Total colour change (ΔE) between 2 measurements were calculated using the formula recommended by CIE (1978):

$$\Delta \mathrm{E} = \sqrt{\Delta \mathrm{L}^2 + \Delta \mathrm{a}^2 + \Delta \mathrm{b}^2} \qquad (14)$$

where ΔL is difference in lightness, Δa is difference in redness and Δb is difference in yellowness between 2 measurements. H and RE was estimated using formula (10) and (11). Closed keeping system, uniform starter diet (1-4 weeks of age, 21-23% crude protein, 11-12 MJ/kg energy, 1.0% Ca, 0.7% P), grower diet (5-20 weeks of age, 15-16% crude protein, 10-11 MJ/kg energy, 1.0% Ca, 0.65% P) and layer diet (from 21 weeks of age, 17-18% crude protein, 11-12 MJ/kg energy, 3.75% Ca, 0.7% P) were

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applied for all genotypes. Birds had free access to feed and clean water. Preventive vaccinations were done as required by national regulation.

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4. STATISTICAL ANALYSIS

Data were first subjected to Levene's test and two-way analysis of variance (ANOVA) test. If variances were equal across groups (significant values in Levene's test are higher than 0.05), the 2-way ANOVA test was expected to give information about the effects of breed, pen and time factors, as well as their interacting effects on studied parameters. Significant differences amongst the average were examined by post hoc Tukey HSD test. In some cases, a t-test was applied to determine the significance of the difference of two data sets. If variances were not equal across groups, Welch's test (unequal variances t-test) was used. All tests were operated by SPSS software (IBM CORP, 2013).

DOI: 10.15477/SZE.WAMDI.2019.003

5. RESULTS AND DISCUSSION

5.1. Population study of 14 old Hungarian poultry breeds

N_m, N_f, estimated N_m/N_f, N_e, N_e/N and ΔF are given in Tables 10, 11, 12, 13 and 14, while N_e and n are shown in Figure 2. There was no PHc, HLgf, WHd, WId breeding stock registered before 2004 and no HUg before 2005. The n of breeds other than HUg, in which n remained unchanged (n = 2), increased year by year, reaching the peak in 2012 (YHc and SHc with n = 10; COt and BRt with n = 9; HLgf with n = 8, PHc, BTc, STc, FHg and WId with n = 7; WHd with n = 5) or in 2013 (WTc with n = 8). From 2013, a slight decrease in the n of most breeds can be seen. Changes are partly due to a new 5-year subsidy system financed by the European Union for in vivo gene conservation of the registered breeds and stocks between 2010 and 2014.

Based on N_m/N_f, studied breeds can be categorised into 2 distinct groups: 1. chicken group that has relatively low N_m/N_f and 2. the group including HLgf, FHg, HUg, WHd, WId, COt, BRt that had relatively high N_m/N_f. N_e varies widely, from 92 (COt in 2000) to 2581 (HLgf in 2012). It is generally higher in the period between 2011 and 2013 in comparison with the other periods of time. However, the N_e of WTc, BTc, STc, WHd and COt always stayed below 1000 individuals. Huge enhancement of N_e can be seen in PHc (from 242 in 2009 to 1640 in 2013), in HLgf (from 633 in 2009 to 2581 in 2012) and in HUg (from 163 in 2010 to 1262 in 2012).

It has been noted that the higher n, the greater N_e is (Figure 7). N_e/N of all breeds is higher than 0.400 and it is highest in HLgf (0.980 in 2008). In case of ΔF, the lowest of 0.019% and highest of 0.794% were recorded in 2012 (HLgf) and 2009 (WHd), respectively. YHc and SHc had a ΔF lower than 0.108% during the entire investigating period. Populations with N_e

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smaller than 100 birds had a ΔF higher than 0.500% (COt in 2000, 2002 and 2004; WHd in 2009). In the last 2 years of analysis, 2014 and 2015, only HUg and WHd had a ΔF higher than 0.200%. Noticeably, there was a gradual decline in the ΔF of PHc, HLgf, COt and BRt. In the breeds studied, except for HUg (n is constant), the n correlate positively with N_e, but negatively with ΔF (Table 14).

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Table 10: Total number of breeding males (N_m) and breeding females (N_f), sex ratio (N_m/N_f), ratio of effective population size and total population size (N_e/N) and inbreeding rate (ΔF) in per cent of YHc (Yellow Hungarian chicken), WHc (White Hungarian chicken), SHc (Speckled Hungarian chicken) and PHc (Partridge Coloured Hungarian chicken) from 2000 to 2015.

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
YHc	N_m	208	300	206	312	255	187	176	182	308	382	243	484	403	529	541	394
	N_f	1597	1610	1700	1979	1736	1669	1605	1507	2067	1787	1317	2123	2761	3362	3063	3059
	N_m/N_f	0.130	0.186	0.121	0.158	0.147	0.112	0.110	0.121	0.149	0.214	0.185	0.228	0.146	0.157	0.177	0.129
	N_e/N	0.408	0.530	0.386	0.471	0.447	0.362	0.356	0.385	0.451	0.580	0.526	0.605	0.445	0.470	0.510	0.404
	ΔF	0.068	0.049	0.068	0.046	0.056	0.074	0.079	0.077	0.047	0.040	0.061	0.032	0.036	0.027	0.027	0.036
WHc	N_m	91	140	79	85	67	57	48	56	58	73	89	151	122	215	124	112
	N_f	509	330	402	415	395	399	342	232	288	318	389	733	839	1292	807	696
	N_m/N_f	0.179	0.424	0.197	0.205	0.170	0.143	0.140	0.241	0.201	0.230	0.229	0.206	0.145	0.166	0.154	0.161
	N_e/N	0.515	0.837	0.549	0.564	0.496	0.438	0.432	0.627	0.558	0.607	0.606	0.567	0.443	0.489	0.462	0.478
	ΔF	0.162	0.127	0.189	0.177	0.218	0.251	0.297	0.277	0.259	0.211	0.173	0.100	0.117	0.068	0.116	0.130
SHc	N_m	247	240	294	277	255	243	200	159	193	135	229	287	273	381	298	269
	N_f	1692	1302	1577	1568	1440	1431	830	714	876	814	1007	1563	1883	2199	2016	1792
	N_m/N_f	0.146	0.184	0.186	0.177	0.177	0.170	0.241	0.223	0.220	0.166	0.227	0.184	0.145	0.173	0.148	0.150
	N_e/N	0.445	0.526	0.530	0.510	0.511	0.496	0.626	0.596	0.592	0.488	0.604	0.524	0.442	0.503	0.449	0.454
	ΔF	0.058	0.062	0.050	0.053	0.058	0.060	0.078	0.096	0.079	0.108	0.067	0.052	0.052	0.038	0.048	0.053
PHc	N_m						60	59	100	96	73	90	193	344	478	392	413
	N_f						322	236	337	328	350	316	864	2371	2886	2662	2521
	N_m/N_f						0.186	0.250	0.297	0.293	0.209	0.285	0.223	0.145	0.166	0.147	0.164
	N_e/N						0.530	0.640	0.706	0.701	0.571	0.690	0.597	0.443	0.488	0.448	0.484
	ΔF						0.247	0.265	0.162	0.168	0.207	0.178	0.079	0.042	0.030	0.037	0.035

Source: HáGK and MGE breeding archives and the Hungarian Poultry Information System, supervised by the National Food Chain Safety Office (the breeding authority of Hungary)

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Table 11: Total number of breeding males (N_m) and breeding females (N_f), sex ratio (N_m/N_f), ratio of effective population size and total population size (N_e/N) and inbreeding rate (ΔF) in per cent of WTc (White Transylvanian Naked Neck chicken), BTc (Black Transylvanian Naked Neck chicken) and STc (Speckled Transylvanian Naked Neck chicken) from 2000 to 2015.

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
WTc	N_m	81	140	78	87	75	59	51	55	58	72	93	150	113	267	165	113
	N_f	519	329	418	399	340	373	302	221	243	255	312	624	892	1643	1087	699
	N_m/N_f	0.156	0.426	0.187	0.218	0.221	0.158	0.169	0.249	0.239	0.282	0.298	0.240	0.127	0.163	0.152	0.162
	N_e/N	0.467	0.838	0.530	0.588	0.592	0.472	0.494	0.638	0.622	0.687	0.708	0.625	0.399	0.481	0.458	0.479
	ΔF	0.178	0.127	0.190	0.175	0.203	0.245	0.286	0.284	0.267	0.223	0.174	0.103	0.125	0.054	0.087	0.129
BTc	N_m	76	140	78	98	77	64	51	56	58	76	90	159	113	243	164	112
	N_f	484	330	418	419	288	289	190	208	289	275	379	654	870	1556	1084	698
	N_m/N_f	0.157	0.424	0.187	0.234	0.267	0.221	0.268	0.269	0.201	0.276	0.237	0.243	0.130	0.156	0.151	0.160
	N_e/N	0.469	0.837	0.530	0.614	0.666	0.594	0.667	0.669	0.557	0.679	0.620	0.629	0.407	0.467	0.457	0.477
	ΔF	0.190	0.127	0.190	0.157	0.206	0.239	0.311	0.283	0.259	0.210	0.172	0.098	0.125	0.059	0.088	0.130
STc	N_m	94	168	119	121	112	107	93	79	90	97	130	199	161	229	169	156
	N_f	506	582	562	613	610	697	510	350	361	361	521	896	934	1222	1023	894
	N_m/N_f	0.186	0.289	0.212	0.197	0.184	0.154	0.182	0.226	0.249	0.269	0.250	0.222	0.172	0.187	0.165	0.174
	N_e/N	0.528	0.695	0.577	0.551	0.524	0.461	0.522	0.601	0.639	0.668	0.639	0.595	0.502	0.532	0.487	0.506
	ΔF	0.158	0.096	0.127	0.124	0.132	0.135	0.159	0.194	0.174	0.163	0.120	0.077	0.091	0.065	0.086	0.094

Source: HáGK and MGE breeding archives and the Hungarian Poultry Information System, supervised by the National Food Chain Safety Office (the breeding authority of Hungary)

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Table 12: Total number of breeding males (N_m) and breeding females (N_f), sex ratio (N_m/N_f), ratio of effective population size and total population size (N_e/N) and inbreeding rate (ΔF) in per cent of HLgf (Hungarian Landrace Guinea Fowl), COt (Copper Turkey) and BRt (Bronze Turkey) from 2000 to 2015.

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
HLgf	N_m						93	85	112	330	262	332	590	855	617	440	340
	N_f						227	215	401	445	400	1099	1701	2631	1798	1510	1508
	N_m/N_f						0.410	0.395	0.279	0.742	0.655	0.302	0.347	0.325	0.343	0.291	0.225
	N_e/N						0.825	0.812	0.683	0.978	0.957	0.713	0.765	0.740	0.761	0.699	0.601
	ΔF						0.189	0.205	0.143	0.066	0.079	0.049	0.029	0.019	0.027	0.037	0.045
COt	N_m	30	44	34	49	31	45	47	77	72	48	105	168	281	290	231	196
	N_f	100	167	92	120	120	167	148	268	220	220	330	527	868	1125	940	770
	N_m/N_f	0.300	0.263	0.370	0.408	0.258	0.269	0.318	0.287	0.327	0.218	0.318	0.319	0.324	0.258	0.246	0.255
	N_e/N	0.710	0.660	0.788	0.824	0.653	0.669	0.732	0.694	0.743	0.588	0.732	0.733	0.739	0.652	0.633	0.647
	ΔF	0.542	0.359	0.504	0.359	0.507	0.353	0.350	0.209	0.230	0.317	0.157	0.098	0.059	0.054	0.067	0.080
BRt	N_m	112	80	102	106	85	78	97	90	83	50	123	194	315	317	251	205
	N_f	440	240	282	329	350	340	286	298	212	210	379	672	972	1208	977	828
	N_m/N_f	0.255	0.333	0.362	0.322	0.243	0.229	0.339	0.302	0.392	0.238	0.325	0.289	0.324	0.262	0.257	0.248
	N_e/N	0.647	0.750	0.780	0.737	0.629	0.607	0.756	0.713	0.809	0.621	0.740	0.695	0.739	0.659	0.650	0.636
	ΔF	0.140	0.208	0.167	0.156	0.183	0.197	0.173	0.181	0.210	0.310	0.135	0.083	0.053	0.050	0.063	0.076

Source: HáGK and MGE breeding archives and the Hungarian Poultry Information System, supervised by the National Food Chain Safety Office (the breeding authority of Hungary)

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Table 13: Total number of breeding males (N_m) and breeding females (N_f), sex ratio (N_m/N_f), ratio of effective population size and total population size (N_e/N) and inbreeding rate (ΔF) in per cent of FHg (Frizzled Hungarian Goose), HUg (Hungarian Goose), WHd (White Hungarian Duck) and WId (Wild Coloured Hungarian Duck) from 2000 to 2015.

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
FHg	N_m	114	146	146	187	165	139	166	96	89	98	145	450	389	396	310	375
	N_f	400	483	382	436	650	518	487	222	214	237	424	1268	1473	1437	1110	1327
	N_m/N_f	0.285	0.302	0.382	0.429	0.254	0.268	0.341	0.432	0.416	0.414	0.342	0.355	0.264	0.276	0.279	0.283
	N_e/N	0.690	0.713	0.800	0.840	0.646	0.667	0.758	0.843	0.830	0.828	0.760	0.773	0.661	0.677	0.683	0.687
	ΔF	0.141	0.111	0.118	0.096	0.095	0.114	0.101	0.187	0.199	0.180	0.116	0.038	0.041	0.040	0.052	0.043
HUg	N_m							121	81	60	60	63	193	201	423	70	85
	N_f							246	180	174	134	115	565	612	1240	251	220
	N_m/N_f							0.492	0.450	0.345	0.448	0.548	0.342	0.328	0.341	0.279	0.386
	N_e/N							0.884	0.856	0.763	0.855	0.915	0.759	0.744	0.759	0.682	0.804
	ΔF							0.154	0.224	0.280	0.302	0.307	0.087	0.083	0.040	0.228	0.204
WHd	N_m						79	43	47	40	21	68	101	186	153	129	76
	N_f						148	106	115	79	63	168	311	550	567	465	290
	N_m/N_f						0.534	0.406	0.409	0.506	0.333	0.405	0.325	0.338	0.270	0.277	0.262
	N_e/N						0.908	0.821	0.824	0.893	0.750	0.820	0.740	0.755	0.669	0.680	0.658
	ΔF						0.243	0.409	0.375	0.471	0.794	0.258	0.164	0.090	0.104	0.124	0.208
WId	N_m						131	77	97	105	118	140	298	341	274	271	101
	N_f						393	317	335	341	369	501	857	1111	840	697	390
	N_m/N_f						0.333	0.243	0.290	0.308	0.320	0.279	0.348	0.307	0.326	0.389	0.259
	N_e/N						0.750	0.629	0.696	0.720	0.734	0.683	0.766	0.719	0.742	0.806	0.654
	ΔF						0.127	0.202	0.166	0.156	0.140	0.114	0.057	0.048	0.061	0.064	0.156

Source: HáGK and MGE breeding archives and the Hungarian Poultry Information System, supervised by the National Food Chain Safety Office (the breeding authority of Hungary)

Table 14: Correlation between the number of registered stocks (n), effective population size (N_e) and inbreeding rate (ΔF) in the populations of traditional Hungarian poultry breeds from 2000 to 2015

Traditional Hungarian poultry breeds	n and N_e		n and ΔF	
	r	Sig.	r	Sig.
YHc	0.861	**	-0.819	**
WHc	0.762	**	-0.687	**
SHc	0.543	**	-0.455	ns
PHc	0.974	**	-0.923	**
WTc	0.850	**	-0.751	**
BTc	0.816	**	-0.722	**
STc	0.767	**	-0.690	**
HLgf	0.868	**	-0.802	**
FHg	0.809	**	-0.644	**
HUg	-	-	-	-
WHd	0.910	**	-0.756	**
WId	0.893	**	-0.808	**
COt	0.972	**	-0.790	**
BRt	0.953	**	-0.753	**

*r: Pearson correlation coefficient, Sig.: Significant level, **: P < 0.01, ns: P > 0.05*
-: cannot compute due to constant number of registered stocks
YHc: Yellow Hungarian chicken; WHc: White Hungarian chicken; SHc: Speckled Hungarian chicken; PHc: Partridge Coloured Hungarian chicken; WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck chicken; HLgf: Hungarian Landrace Guinea Fowl; FHg: Frizzled Hungarian Goose, HUg: Hungarian Goose; WHd: White Hungarian Duck; WId: Wild Coloured Hungarian Duck; COt: Copper Turkey; BRt: Bronze Turkey

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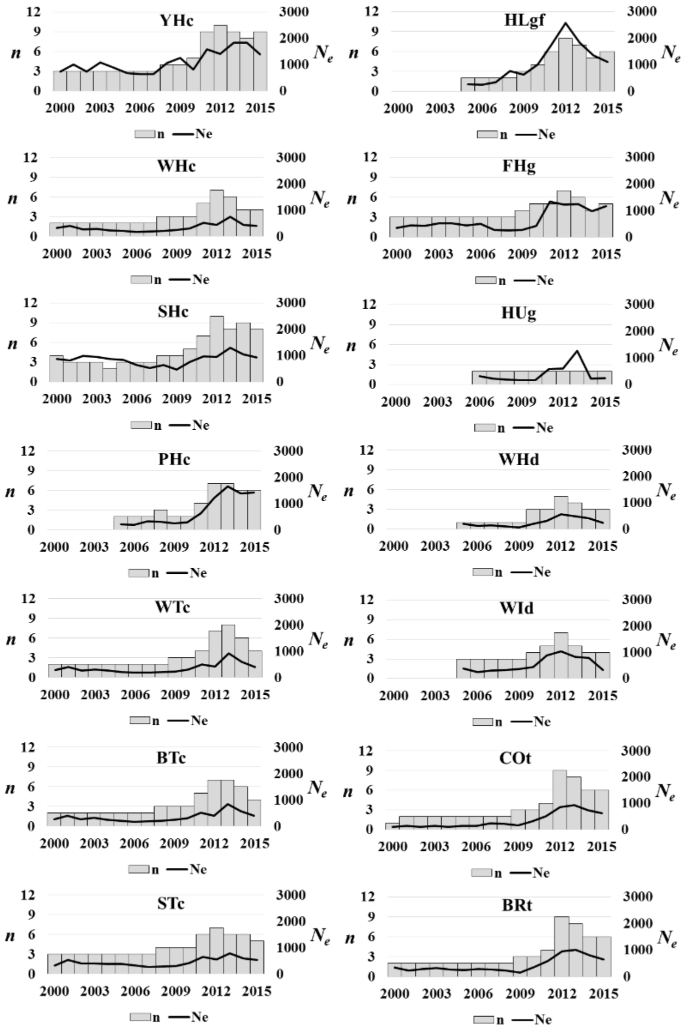

Figure 7. Changes in the number of registered stocks (n) and effective population size (N_e) of local Hungarian poultry breeds from 2000 to 2015

(YHc: Yellow Hungarian chicken; WHc: White Hungarian chicken; SHc: Speckled Hungarian chicken, PHc: Partridge Coloured Hungarian chicken, WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck chicken, HLgf: Hungarian Landrace Guinea Fowl, FHg: Frizzled Hungarian goose, HUg: Hungarian goose, WHd: White Hungarian duck, WId: Wild Coloured Hungarian duck, COt: Copper turkey, BRt: Bronze turkey)

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According to MEUWISSEN and WOOLIAMS (1994), the N_e of 30 to 250 is needed for natural selection to compensate inbreeding depression. LYNCH et al. (1995) suggested that the N_e of rare breeds should exceed 500 animals, otherwise the accumulation of deleterious mutations may cause extinction. FAO (2013) recommended a minimum N_e of 50 to guarantee a short or medium-term survival and over 50 individuals for a long-term survival of a population.

In this study, 11 Hungarian poultry breed recently had N_e higher than 500 and 6 breeds (WHc, WTc, BTc, HUg, WHd and WId) had N_e lower than 500. No breed studied had N_e below 50. This result is much better than that of Belgian chickens reported by LARIVIERE et al. (2011), in which only 3 breeds were reported to have the N_e of more than 500 individuals.

It was noticed that when N_m/N_f was close to 1.00, the N_e was nearly equal to the population size. This outcome confirmed a statement by ZANON and SABBIONI (2001) that increasing N_m in the population so that it is as close as possible to N_f is helpful for maximising N_e. If compared to some other European local poultry breeds such as the Polish (ΔF up to 0.20%), Slovakian (ΔF up to 0.71%), Belgian (ΔF up to 0.94%) and Spanish breeds (ΔF up to 0.70%) or commercial breeds (ΔF up to 0.60%), (AMELI et al., 1991; CAMPO et al., 2000; SPALONA et al., 2007; LARIVIERE et al., 2011) the ΔF of Hungarian breeds can be considered fairly low. If such ΔF can be maintained for the long term, then Hungarian local poultry breeds will have less risks of becoming extinct (SIMON and BUCHENAUER, 1993).

Results on the trends of population data of old Hungarian poultry breeds between 2000 and 2015 show the effectiveness of Hungarian poultry conservation strategy, as suggested in a recent molecular genetic study of BODZSAR et al. (2009), with the minimum of 10 families or lines/breed, a rotational use of sires, the male/female ratio of 1:7 for chicken, 1:5 for guinea fowl and 1:4 for turkey, goose and duck applied in conserved flocks.

This study also reflects the significance of the number of stocks (n) in breed conservation, which is proposed by the authors to be 10 or more and suggest the subsidy system of local breeds to change in a way that helps increasing n. In case of very low n (e.g. HUg), if a main breeding stock drops out from the programme for any reason, it would lead to a marked fall in N_e. More importantly, since most of the conservation programmes are subsidised by international bodies (the EU in the case of the Hungarian conservation programme) for a strict period with limited additional local support, getting close to the end of a funding period (e.g. 2013), reduction of n and N_e is undoubtedly inevitable. Additionally, it should be taken into consideration that the size of breeding stocks was not homogenous. According to stock holder capacity, the size varied from below 50 to over 1000. In a small breeding stock, the ΔF formula used offers very limited future predictions. And, at the same time, the small population size may affect the justification of the correlation between n and either N_e or ΔF.

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5.2. Egg production study of 7 indigenous Hungarian chicken breeds

The number of eggs/hen/day was consistently high in WHc and YHc, and consistently low in STc (Table 15). All hens of the 7 breeds, hatched in May, started to lay eggs in October, and ended in June of the following year. Interestingly, in 2009-2010, most of the breeds, apart from the STc chicken, showed similar egg producing pattern over the laying period (Figure 8).

Table 15: Eggs/hen/day of 7 traditional Hungarian chicken breeds in 2008-2009 and 2009-2010

Year	Breed	n	Mean ± sd		Significant level
2008-2009	YHc	220	0.455^{b}	± 0.169	*
	WHc	220	0.468^{a}	± 0.141	
	SHc	220	0.356^{d}	± 0.155	
	PHc	220	0.446^{c}	± 0.134	
	WTc	220	0.318^{f}	± 0.171	
	BTc	220	0.320^{e}	± 0.168	
	STc	220	0.316^{g}	± 0.178	
2009-2010	YHc	233	0.493^{a}	± 0.165	*
	WHc	233	0.410^{b}	± 0.142	
	SHc	233	0.349^{c}	± 0.167	
	PHc	233	0.262^{g}	± 0.148	
	WTc	233	0.321^{e}	± 0.190	
	BTc	233	0.327^{d}	± 0.180	
	STc	233	0.269^{f}	± 0.203	

YHc: Yellow Hungarian chicken, WHc: White Hungarian chicken, SHc: Speckled Hungarian chicken, PHc: Partridge Coloured Hungarian chicken, WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck Chicken

*: $P<0.05$

$^{a, b, c, d, e, f, g}$: *different superscript letters show significant differences between groups*

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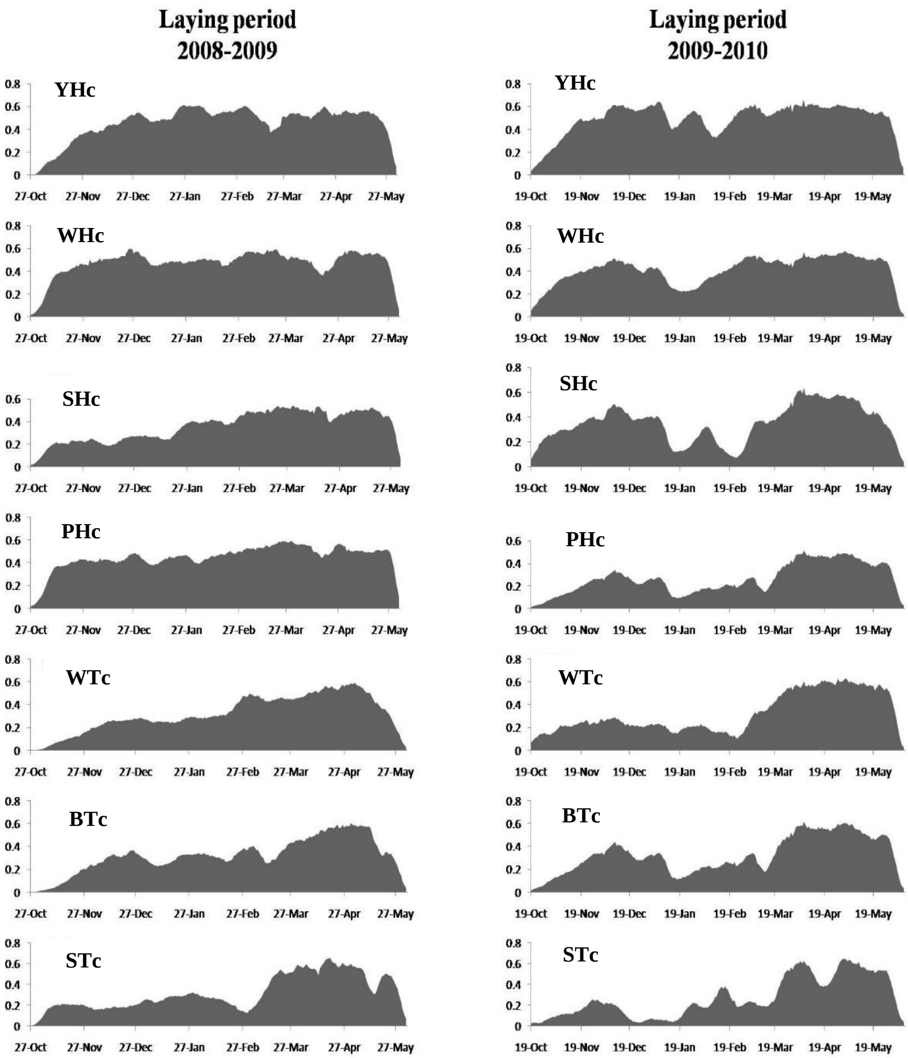

Figure 8. Eggs/hen/day of two subsequent generations of 7 Hungarian chicken breeds in the 1st laying period, in 2008-2009 and 2009-2010

YHc: Yellow Hungarian chicken, WHc: White Hungarian chicken, SHc: Speckled Hungarian chicken, PHc: Partridge Coloured Hungarian chicken, WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck Chicken

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It was observed that the laying cycle of these breeds was divided into two sub-periods, in which the number of eggs increased till a particular value and then dropped, which resulted in the formation of a 2-hill appearance. The trend line of STc chicken breed showed only one peak in April-May with a steep increase, starting from December. All the Transylvanian hens tended to produce much fewer eggs during wintertime (October-February) than the other groups (Figure 8). The difference between egg production during winter and spring was not clearly demonstrated in YHc, SHc, WHc and PHc chicken breeds. From 2010 to 2012, number of eggs produced in the 1st and the 2nd laying periods was recorded (Table 16).

Table 16: Eggs/hen/day of 7 traditional Hungarian chicken breeds in the 1st and the 2nd laying period in 2011 and 2012

Breeds	Laying period	n	Mean ± sd		Significance
YHc	1st	181	0.454	± 0.159	ns
	2nd	181	0.473	± 0.111	
WHc	1st	181	0.427^{a}	± 0.153	*
	2nd	181	0.384^{b}	± 0.125	
SHc	1st	181	0.459^{a}	± 0.144	*
	2nd	181	0.386^{b}	± 0.145	
PHc	1st	181	0.483	± 0.119	ns
	2nd	181	0.490	± 0.125	
WTc	1st	178	0.375	± 0.149	ns
	2nd	178	0.375	± 0.157	
BTc	1st	179	0.319^{b}	± 0.153	*
	2nd	179	0.379^{a}	± 0.154	
STc	1st	181	0.306^{b}	± 0.176	*
	2nd	181	0.416^{a}	± 0.127	

YHc: Yellow Hungarian chicken (YH), WHc: White Hungarian chicken, SHc: Speckled Hungarian chicken, PHc: Partridge Coloured Hungarian chicken, WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck Chicken
*ns: not significant; *: P<0.050*
$^{a,\,b}$*: different superscript letters show significant differences between groups*

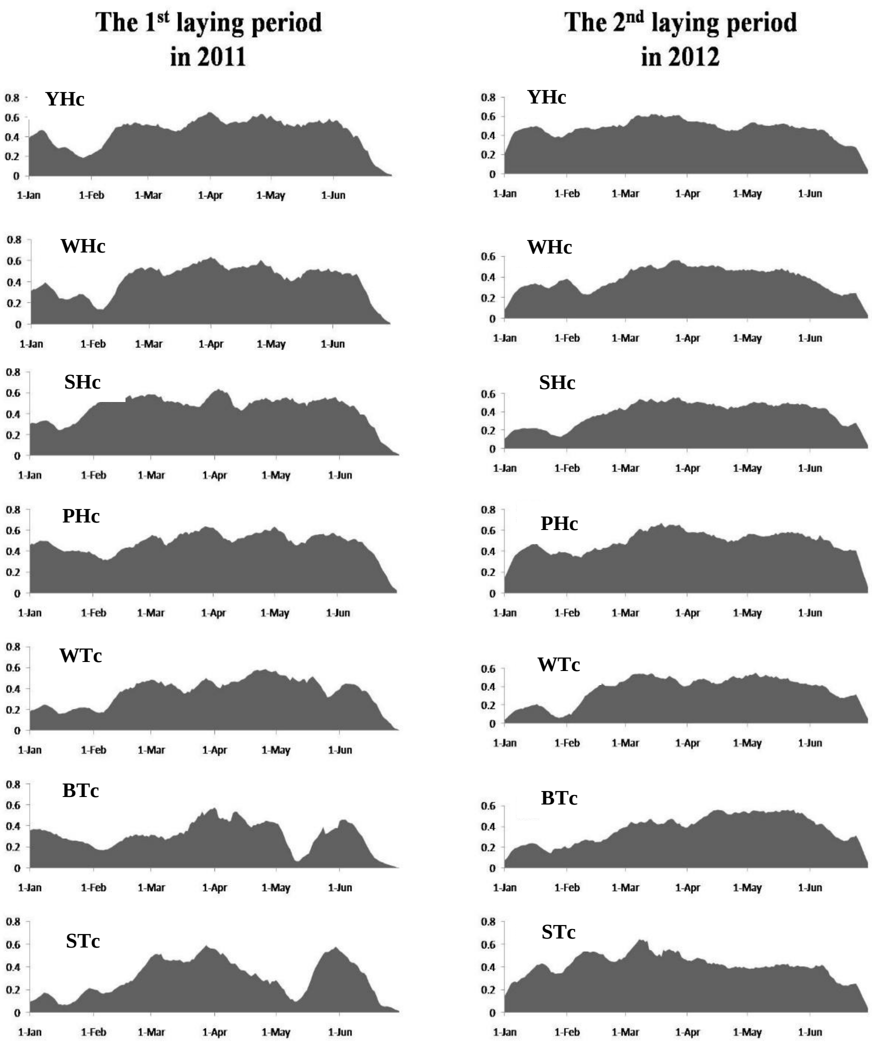

Figure 9. Eggs/hen/day of the same flocks of 7 Hungarian chicken breeds in the 1st (2011) and the 2nd (2012) laying period

YHc: Yellow Hungarian chicken, WHc: White Hungarian chicken, SHc: Speckled Hungarian chicken, PHc: Partridge Coloured Hungarian chicken, WTc: White Transylvanian Naked Neck chicken, BTc: Black Transylvanian Naked Neck chicken, STc: Speckled Transylvanian Naked Neck Chicken (STc)

The significant difference between the two subsequent laying periods of the same flocks was found only in SHc, WHc, STc and BTc chicken breeds. However, age effect on these chicken breeds was not the same (Figure 9). The STc and BTc hens produced significantly higher number of eggs/day during the 2nd laying period than during the 1st one (0.306 vs. 0.416, $P<0.050$ and 0.319 vs. 0.379, $P<0.050$ respectively). On the contrary, the SHc and WHc hens laid a significantly lower number of eggs during their 2nd laying period as compared with their 1st laying period (0.459 vs. 0.386, $P<0.050$ and 0.427 vs. 0.384, $P<0.050$ respectively).

Since the WHc and YHc breeds showed higher egg production than the others, these breeds would be preferred for free range extensive and ecology-oriented egg-farming systems. In this study, we also found that most of the traditional Hungarian hens, being hatched in spring, produced a high number of eggs from March to May, whereas the opposite was true in the beginning, between December and February and at the end of their egg production cycle. This observation could be explained by the day length increase in spring (March-May) and decrease in December.

Changes of day length would stimulate the egg production of hens to rise and drop respectively. This observation agrees with the previous studies of JACOB et al. (1998), and OBAYELU and ADENIYI (2006) that only increasing natural light would resume egg production. However, varied fluctuations during the egg laying period were obtained in different traditional Hungarian chicken breeds. It confirmed the result found in the studies of OLAWUMI and OGUNLADE (2013) that the performance in terms of egg production varies with seasons between breeds or strains.

Moreover, it was observed that the Transylvanian hens consistently produced much lower number of eggs in the winter. Therefore, the study

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concluded that the Transylvanian chicken breeds are more sensitive to low temperature than the other breeds. Regarding the number of eggs produced during the 1st and the 2nd lay, this study partly supported the results of JOYNER et al. (1987), JACOB et al. (1998), SCHRIDER (2007) and BENK et al. (2008) that the rate of egg production reduced with increasing hen's age only in cases of SHc and WHc hens.

On the contrary, the STc and BTc chicken breeds showed dissimilar results. In which, the rate of egg production increased with increasing hen's age. No significant difference could be found in other breeds. The somewhat different and shorter breeding history of the Transylvanian naked neck chicken breeds (BODÓ et al., 1990, SZALAY, 2002) may result in lower egg production in the first and comparatively higher one in the subsequent production period. However, further investigation of age effect on production and reproduction characteristics of traditional Hungarian chicken breeds is recommended.

Furthermore, the genetic diversity of Hungarian chicken breeds based on microsatellite marker studies by BODZSAR et al. (2009) can be observed in the different egg production patterns of the breeds, mainly between Hungarian and Transylvanian Naked Neck breed groups. Presuming that the differences originate primarily from the natural selection during their breed formation in the last decades, studies should be also undertaken to elaborate the breeding conditions to the propagation of family poultry farming and other sustainable uses of all the breeds.

5.3. Adaptation study of Partridge Coloured Hungarian chicken in the subtropics

The Live% of birds was relatively high, both at 12 weeks of age (92.0% for HU and 96.2% for VN), and during the laying period (between 24 and 54 weeks of age, 93.5% for HU and 96.6% for VN). No significant difference in survival rate was obtained. The results of growth performance revealed that difference in body weight between the HU and VN flocks was negligible in the first two months of rearing (4 and 8 weeks of age). However, at the age of 12 weeks (recommended earliest age for slaughtering in Hungary), while male birds of both the HU and VN flocks had comparable body weight, HU females were significantly heavier than VN females.

Furthermore, compared with the VN flock, the HU flock had a significantly higher FCR. Regarding slaughter results, place of rearing had little effect on the percentages of eviscerated carcass and deboned thigh meat. However, it led to significant differences in the percentage of deboned breast meat (Table 17). Regarding egg production, eggs produced by HU layers were of greater weight compared to eggs produced by VN layers. However, VN layers laid 28 more eggs, thus, their calculated egg mass per hen was markedly superior (Table 17).

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Table 17: Summary of result on survival rate, meat production at the age of 12 weeks, egg production and egg quality of Partridge Coloured Hungarian chicken reared parallel at the Research Centre for Farm Animal Gene Conservation in Hungary (HU) and at Thuy Phuong Poultry Research Centre for adaptation study in sub-tropic climatic zone of North Vietnam (VN).

Parameters		HU Mean ± SE	VN Mean ± SE	Significance
Liveability	at 12 weeks of age (%)	96.2 ± 0.76	95.0 ± 0.80	t-test, ns
	between 24 and 54 weeks of age (%)	93.5 ± 1.7	96.5 ± 1.3	t-test, ns
Body weight	of male birds at 12 weeks of age (g)	1428.5 ± 12.2	1411.8 ± 4.4	t-test, ns
	of female birds at 12 weeks of age (g)	1198 ± 12.7	1093 ± 2.3	t-test, **
FCR at 12 weeks of age (kg feed/kg body weight gain)		3.6 ± 0.01	3.4 ± 0.01	t-test, **
Eviscerated carcass percent at 12 weeks of age (%)		75.8 ±0.08	75.6 ± 0.06	t-test, ns
Deboned breast per cent of male birds at 12 weeks of age (%)		17.0 ± 0.01	16.7 ± 0.12	Welch test, *
Deboned thigh percent of female birds at 12 weeks of age (%)		27.9 ± 0.15	28.2 ± 0.04	Welch test, ns
Weeks of age when	1st egg was laid	24	24	
	egg production reached 30%	29-30	29-30	
	egg production reached 50%	44	34	
Number of produced eggs/layer/7 months		83.3 ± 0.16	111.7 ±0.05	t-test, **
Egg weight (g)		58.3 ± 1.4	54.9 ± 0.63	t-test, ns
Egg mass/layer/7 months (kg)		4.9 ± 0.11	6.1 ± 0.07	t-test, **
Egg yolk weight (g)		16.4 ± 0.74	16.2 ± 0.26	Welch test, ns
Egg albumen weight (g)		36.0 ± 0.73	30.3 ± 0.14	Welch test, **
Egg shell weight (g)		5.9 ± 0.22	6.8 ± 0.31	T-test, ns
Egg length (cm)		5.8 ± 0.10	4.8 ± 0.06	T-test, **
Egg width (cm)		4.3 ± 0.03	4.2 ± 0.03	T-test, ns
Egg shape index (%)		74.1 ± 0.02	87.5 ± 0.01	T-test, **

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Figure 10 demonstrates the egg producing patterns of the two flocks. Their EP was comparable in the first 2 months of laying. In the 3rd month, differences became significantly apparent (HU: 44.8 ± 3.6% and VN: 53.5 ± 9.9%, Welch test, P<0.01). From that point onwards, the EP of HU hens gradually increased and reached the highest point in the 7th month (58.7 ± 2.5%). In contrast, the EP of VN hens peaked in the 4th month (69.3 ± 4.1%) and was persistently greater than 50% until the 7th month. Fertility, hatchability and the percentage of standard hatchlings of eggs produced by the two flocks were relatively commensurate (HU: 96.7 ± 0.50%, VN: 96.0 ± 0.99%, for fertility; HU: 84.6 ± 5.2%, VN: 85.9 ± 2.9%, for hatchability and HU: 80.2 ± 5.4%, VN: 81.9 ± 3.2%, for substandard hatchlings). Nonetheless, it was noted that HU eggs showed less cases of embryonic disorders than VN ones (8.4 ± 1.3% vs. 10.1 ± 2.6%, t-test, P<0.05).

The percentage of egg white and egg shell was significantly different between the two flocks (HU: 61.8 ± 0.68%, VN: 55.3 ± 0.61%, t-test, P<0.01 for egg white and HU: 10.3 ± 0.39%, VN: 12.3 ± 0.60%, t-test, P<0.05 for eggshell). However, no significant difference was found when comparing the percentage of egg yolk between the two flocks (HU: 28.1 ± 0.91%, VN: 29.6 ± 0.31%). Furthermore, variation in the size of eggs among the two flocks was noticeable (Table 17). Results of estimated egg shape index suggested that the eggs of HU hens were rounder than those of VN hens.

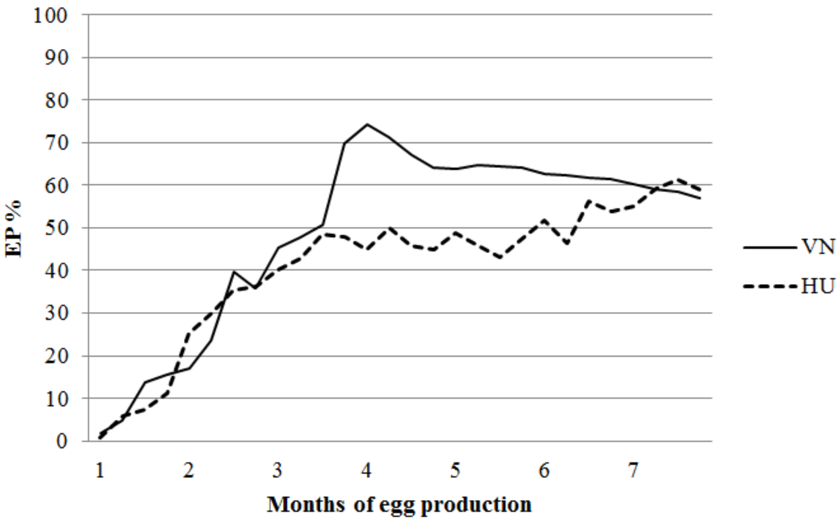

Figure 10. Egg producing patterns of the 1st egg laying period, started in November, of Partridge Coloured Hungarian chicken reared parallel at the Research Centre for Farm Animal Gene Conservation in Hungary (HU) and at Thuy Phuong Poultry Research Centre for adaptation study in sub-tropic climatic zone of North Vietnam (VN)

With the same husbandry employed at both locations, the high survival rate, overall productivity and reproductive ability of the VN flock confirmed the adaptive potential of PHc to subtropical climates. The comparable body weight and slaughtering yield (eviscerated carcass and deboned thigh) of male birds makes the involvement of PHc in subtropical poultry production promising. The advantages of increased number of eggs and total egg mass produced per layer, with considerably high fertility and hatchability, outweigh the drawback of reduced egg size. The present study is in accordance with former results found for guinea fowl and turkeys taken to Vietnam as old Hungarian poultry breeds for adaptation

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studies (DONG XUAN et al. 2008; TIEN et al. 2010). Noticeably, in comparison with the HU flock, the higher egg production of the VN flock tended to associate with smaller, lighter and relatively longer eggs. This variation may be explained by climatic factors, as identified when collating sunlight duration data and egg production results. For instance, the longer the sunlight duration, the higher the number of eggs produced by HU layers. Furthermore, in the case of the VN flock, the shortest sunlight duration was recorded in the 3rd month of egg production (January 2011). This stimulus might have led to a sudden drop in VN egg production in the following month (4th month of egg production, February 2011). Additionally, the heavier egg shells produced by the VN flock may also result from a positive reaction to the different climate. Heavier eggshell indicates better protection again deleterious environmental factors. Although this type of study was described by MARSHALL (2014) as a neglected area of research, it emphasises the possibility of an agroecological way (ARCHIMEDE et al., 2014) to integrate poultry breeds that are native in the Carpathian Basin in the subtropics. It involves the ex situ protection and utilisation of an old, exotic chicken breed with special respect to conservation and sustainability (SZALAY et al., 2009).

Considering that breeds well adapted to higher temperatures and lower quality diets may become more widely used (HOFFMANN, 2010), the study may provide additional data for the climate change mitigation strategies of both Hungary and Vietnam. Further studies of egg and meat quality, as well as the crossing of PHc with Vietnamese indigenous breeds for sustainable, traditional production purposes, as described by DONG XUAN et al. (2006) are recommended to strengthen the breeding and conservation of the PHc breed.

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5.4. Crosses of Partridge Coloured Hungarian and a natively different Hungarian chicken breed

Live% without significant difference amongst genotypes of 87.5% for (♂ WTc x PHc and ♀ WTc x PHc), 92.5% (♂ PHc, ♀ PHc, ♂ WTc and ♀ WTc), 95.0% (♂ PHc x WTc and ♀ PHc x WTc) was recorded at the end of the experiment. According to ANOVA test, the impact of gender and genotype on average BW, FCR, eviscerated carcass, breast and thigh weight was apparent in all analyses (at 12, 14 and 16 weeks of age, $P<0.01$). Significant interaction effect of genotype and gender was seen on FCR (at 12, 14 and 16 weeks of age, $P<0.01$). The appearance of ♂ WTc x PHc, ♀ WTc x PHc, ♂ PHc x WTc and ♀ PHc x WTc are shown in Figure 11.

Figure 11. The appearance crossbreds in the crosses between Partridge Coloured Hungarian chicken (PHc) and White Transylvanian Naked Neck chicken (WTc)

Body weight, FCR and slaughtering yields at 12, 14, and 16 weeks of age of all genotypes are summarised in Table 18, Table 19 and Table 20, respectively. The results revealed that male chickens have significantly higher BW and lower FCR, in comparison with females. The average BW and FCR of ♂ PHc, ♂ PHc x WTc and ♂ WTc x PHc were superior to the other groups. At the end of the rearing period, the highest BW and lowest FCR was obtained in ♂ PHc while the lowest BW and highest FCR belonged to ♀ WTc. Crossbreds' results were significantly better than those of WTc, but rather comparable to PHc purebreds. A mere difference in terms of BW and FCR could be seen between ♂ PHc x WTc and ♂ WTc x PHc, ♀ PHc x WTc and ♀ WTc x PHc. The highest weight of eviscerated carcass, breast and thigh meat was achieved in ♂ PHc, ♂ WTc x PHc and ♀ PHc x WTc while the lowest was observed in ♀ WTc. However, ♀ WTc owned the highest eviscerated carcass in percentage calculated based on live weight.

Table 18: Average body weight and feed conversion ratio (FCR) of both male and female progeny of Partridge Coloured Hungarian chickens, White Transylvanian Naked Neck chickens (♂ PHc, ♀ PHc, ♂ WTc and ♀ WTc), the cross between Partridge Coloured Hungarian cockerels and White Transylvanian Naked Neck hens (♂ PHc x WTc and ♀ PHc x WTc) and the cross between White Transylvanian Naked Neck cockerels and Partridge Coloured Hungarian hens (♂ WTc x PHc and ♀ WTc x PHc) at 12, 14, 16 weeks of age.

Traits	Age					
	12 wks		14 wks		16 wks	
	Mean	sd	Mean	sd	Mean	sd
Body weight (g)						
♂ PHc	1336^{a}	31.7	1688^{a}	31.24	2051^{a}	56.7
♀ PHc	992^{c}	36.3	1238^{c}	50.34	1457^{c}	55.9
♂ WTc	1181^{b}	14.7	1455^{b}	13.50	1712^{b}	53.0
♀ WTc	869^{d}	32.3	1031^{d}	41.15	1156^{d}	54.9
♂ PHc x WTc	1269^{ab}	37.9	1568^{ab}	80.30	1854^{b}	55.6
♀ PHc x WTc	1029^{c}	15.9	1246^{c}	29.72	1410^{c}	37.0
♂ WTc x PHc	1244^{ab}	26.3	1557^{ab}	64.56	1845^{b}	36.2
♀ WTc x PHc	989^{c}	13.7	1180^{c}	35.79	1358^{c}	51.5
ANOVA test, P value	<0.01		<0.01		<0.01	
FCR (kg feed/kg BW gain)						
♂ PHc	2.11^{d}	0.10	2.37^{d}	0.11	2.59^{d}	0.06
♀ PHc	2.84^{a}	0.10	3.19^{b}	0.15	3.60^{b}	0.16
♂ WTc	2.21^{cd}	0.03	2.69^{c}	0.01	3.05^{c}	0.10
♀ WTc	2.91^{a}	0.10	3.71^{a}	0.13	4.48^{a}	0.19
♂ PHc x WTc	2.01^{d}	0.17	2.47^{cd}	0.18	2.79^{cd}	0.19
♀ PHc x WTc	2.46^{bc}	0.04	3.06^{b}	0.08	3.64^{b}	0.10
♂ WTc x PHc	2.09^{d}	0.06	2.53^{cd}	0.05	2.86^{cd}	0.08
♀ WTc x PHc	2.50^{b}	0.03	3.12^{b}	0.08	3.72^{b}	0.18
ANOVA test, P value	<0.01		<0.01		<0.01	

a, b, c, d: different letters in the same column denote significant differences (P<0.05) among treatments, detected by post hoc Tukey HSD test, wks: weeks

Table 19: Eviscerated carcass in gram and percentage of both male and female progeny of Partridge Coloured Hungarian chickens, White Transylvanian Naked Neck chickens (♂ PHc, ♀ PHc, ♂ WTc and ♀ WTc), the cross between Partridge Coloured Hungarian cockerels and White Transylvanian Naked Neck hens (♂ PHc x WTc and ♀ PHc x WTc) and the cross between White Transylvanian Naked Neck cockerels and Partridge Coloured Hungarian hens (♂ WTc x PHc and ♀ WTc x PHc) at 12, 14, 16 weeks of age.

Parameters	Age					
	12 wks		14 wks		16 wks	
	Mean	sd	Mean	sd	Mean	sd
Eviscerated carcass (g)						
♂ PHc	1080^{a}	108.3	1288^{a}	79.3	1335^{a}	107.0
♀ PHc	815^{cd}	106.7	957^{b}	72.7	1008^{cd}	106.2
♂ WTc	858^{c}	57.7	982^{b}	61.8	1214^{abc}	108.3
♀ WTc	653^{d}	60.6	795^{d}	32.7	876^{d}	62.6
♂ PHc x WTc	1030^{ab}	108.3	1273^{a}	77.9	1203^{abc}	117.0
♀ PHc x WTc	798^{cd}	69.4	881^{cd}	69.0	1263^{ab}	108.1
♂ WTc x PHc	907^{bc}	61.0	1149^{a}	71.2	1310^{a}	80.7
♀ WTc x PHc	762^{cd}	54.7	919^{cd}	75.7	1051^{bc}	110.5
ANOVA test, P value	<0.01		<0.01		<0.01	
Eviscerated carcass (%)						
♂ PHc	79.4	1.7	78.6^{c}	0.4	79.7^{cd}	0.8
♀ PHc	78.4	1.3	79.7^{bc}	1.3	78.9^{d}	1.1
♂ WTc	80.4	2.3	81.8^{a}	1.0	81.6^{b}	1.0
♀ WTc	80.1	1.2	80.8^{ab}	1.1	83.5^{a}	1.4
♂ PHc x WTc	83.1	6.0	80.2^{bc}	0.8	80.4^{bcd}	1.2
♀ PHc x WTc	81.7	4.5	80.1^{bc}	0.9	81.5^{b}	1.0
♂ WTc x PHc	78.1	4.1	79.7^{bc}	0.9	80.4^{bcd}	1.3
♀ WTc x PHc	80.8	1.1	80.8^{ab}	1.4	80.9^{bc}	1.4
ANOVA test, P value	0.06		<0.01		<0.01	

a, b, c, d: different letters in the same column denote significant differences (P<0.05) among treatments, detected by post hoc Tukey HSD test; wks: weeks

Table 20: Breast and thigh meat yield of both male and female progeny of Partridge Coloured Hungarian chickens, White Transylvanian Naked Neck chickens (♂ PHc, ♀ PHc, ♂ WTc and ♀ WTc), the cross between Partridge Coloured Hungarian cockerels and White Transylvanian Naked Neck hens (♂ PHc x WTc and ♀ PHc x WTc) and the cross between White Transylvanian Naked Neck cockerels and Partridge Coloured Hungarian hens (♂ WTc x PHc and ♀ WTc x PHc) at 12, 14, 16 weeks of age.

Parameters	Age					
	12 wks		14 wks		16 wks	
	Mean	sd	Mean	sd	Mean	sd
Breast meat weight (g)						
♂ PHc	193[a]	27.4	250[a]	31.1	260[a]	23.3
♀ PHc	152[bc]	20.7	187[c]	30.4	201[bc]	26.0
♂ WTc	144[c]	14.0	190[bc]	14.5	253[a]	31.2
♀ WTc	131[c]	17.3	171[c]	19.9	191[c]	10.6
♂ PHc x WTc	177[ab]	34.4	249[a]	16.0	239[ab]	48.7
♀ PHc x WTc	150[bc]	11.5	184[c]	18.2	265[a]	39.0
♂ WTc x PHc	161[bc]	17.9	221[ab]	23.6	269[a]	13.9
♀ WTc x PHc	149[bc]	10.8	195[bc]	14.6	235[abc]	32.5
ANOVA test, P value	<0.01		<0.01		<0.01	
Thigh meat weight (g)						
♂ PHc	292[a]	46.8	350[a]	44.5	376[a]	55.7
♀ PHc	213[cd]	32.9	251[cd]	43.1	268[cd]	41.8
♂ WTc	231[bc]	28.0	277[bc]	24.0	356[ab]	35.3
♀ WTc	175[d]	23.9	209[d]	22.8	240[d]	19.7
♂ PHc x WTc	278[ab]	54.5	348[a]	29.6	337[abc]	84.1
♀ PHc x WTc	216[cd]	24.3	226[d]	18.4	343[abc]	67.4
♂ WTc x PHc	243[abc]	18.8	315[ab]	27.2	377[a]	30.5
♀ WTc x PHc	198[cd]	17.00	239[cd]	18.9	281[bcd]	33.8
ANOVA test, P value	<0.01		<0.01		<0.01	

[a, b, c, d]: different letters in the same column denote significant differences (P<0.05) among treatments, detected by post hoc Tukey HSD test; wks: weeks

Data provided in Table 21 represent H and RE of crossbreds in terms of BW, FCR and slaughtering yields. Positive H of BW and slaughtering yields and negative H of FCR were observed in all female crossbreds except for ♀ WTc x PHc's thigh meat weight. In case of male crossbreds, noticeable positive H of slaughtering yields and negative H of FCR could be found in ♂ WTc x PHc and ♂ PHc x WTc, respectively. Nonetheless, it was hard to cumulatively conclude the RE on other traits due to the heterogeneity of the outcome.

Overall, the use of local chicken breeds as parents for crossings may provide an advantage with regards to BW and FCR traits, as it has been found for meat and egg production for chicken (IRAQI, 2008; KONRÁD et al, 2007; KEAMBOU et al., 2010; UDEH, 2015), for duck (VELEZ et al., 1996) and for local guinea fowl (OKE et al., 2012), as the higher degree of heterozygosity of the crossed offspring compared to their parents is mostly the reason for heterosis in certain traits (FAIRFULL, 1990; WILLIAMS et al., 2002). In other words, two Hungarian chicken breeds marked in the same category "indigenous and rare" possess realistic option for genetic improvement by crossings based generally on their genetic diversity, as revealed by BODZSÁR et al. (2009).

The results obtained from this study support the dissemination practice and prospects including HU-BA production system of old Hungarian chicken breeds kept under genetic conservation programme (SZALAY et al., 2009), in which the utilisation of traditional breeds is a major concern and decisions on crossing partners should be made based on both their production and reproduction traits to find the proper genotype for use. Furthermore, crossings may draw certain local breeds with low performance into special production programmes, especially if phenotypic markers advantageous in some way for marketing of final products appear (e.g. mostly uniform white plumage with some brownish shade or heterozygote naked neck appearance), which was the case in this experiment. Practical considerations based on the egg production profiles of purebreds, as well as on RE results obtained in this study, PHc with higher egg production is proposed as female and WTc as male parent for production in cross.

Regarding that old Hungarian chicken breeds belong to the dual-purpose category (SZALAY, 2015), which determines the traditional practical use of genders (males are mostly kept for meat, while females for egg production), concern on how and to what extent the reciprocal crossing affects the expression of reproductive traits can be still the subject of a further study, nevertheless heterosis is usually greater for reproduction traits than for BW (FAIRFULL, 1990). Considering that, no selection is applied in gene bank stocks, crossings of the same category of chickens can be a reasonable tool to improve low productivity and ensure utilisation of a highly threatened breed without making a compromise in product quality of old breeds.

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Table 21: Heterosis (H) and reciprocal effect (RE) calculated for body weight, feed conversion ratio and eviscerated carcass, breast and thigh weight of both male and female progeny of Partridge Coloured Hungarian chickens, White Transylvanian Naked Neck chickens (♂ PHc, ♀ PHc, ♂ WTc and ♀ WTc), the cross between Partridge Coloured Hungarian cockerels and White Transylvanian Naked Neck hens (♂ PHc x WTc and ♀ PHc x WTc) and the cross between White Transylvanian Naked Neck cockerels and Partridge Coloured Hungarian hens (♂ WTc x PHc and ♀ WTc x PHc) at 12, 14, 16 weeks of age.

		H				RE	
Age	Traits	♂ PHc x WTc	♂ WTc x PHc	♀ PHc x WTc	♀ WTc x PHc	(♂ PHc x WTc - ♂ WTc x PHc)	(♀ PHc x WTc - ♀ WTc x PHc)
12 wks	BW	0.79	-1.17	10.54	6.24	24.74	39.95
	FCR	-6.71	-3.32	-14.46	-13.18	-0.07	-0.04
	Cw	6.29	-6.42	8.73	3.78	123.16	36.31
	Bw	5.33	-4.58	6.13	5.28	16.70	1.20
	Tw	6.32	-7.15	11.23	2.05	35.18	17.80
14 wks	BW	-0.22	-0.96	9.80	3.98	11.65	66.04
	FCR	-2.26	-0.04	-11.42	-9.53	-0.06	-0.07
	Cw	12.21	1.26	0.53	4.84	124.34	-37.74
	Bw	13.14	0.28	3.20	9.34	28.30	-10.98
	Tw	11.08	0.45	-1.79	4.15	33.34	-13.66

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16 wks	BW	-1.48	-1.91	7.93	3.95	8.03	52.04
	FCR	-1.05	1.24	-9.93	-7.91	-0.06	-0.08
	Cw	-5.59	2.77	34.11	11.54	-106.53	212.58
	Bw	-6.56	5.10	35.62	19.89	-29.86	30.79
	Tw	-7.88	2.99	35.14	10.80	-39.76	61.79

BW: body weight; FCR: feed conversion ratio; Cw: Eviscerated carcass weight, Bw: deboned breast weight; Tw: deboned thigh weight; wks: weeks

5.5. Crosses of Partridge Coloured Hungarian and an old chicken breed of distant origin

No mortality was observed during the laying period. In 12-week rearing period, the Live% of birds kept in si, sf and cf systems ranged between 94.0-96.7%, 95.0-97.5% and 95.0-96.2% respectively, without significant difference among the genotypes and keeping systems. The appearance of crossbreds in the crosses between ♂MIc and ♀PHc is shown in Figure 12.

Figure 12. The appearance crossbreds in the crosses between and Vietnamese Mia cockerel (♂MIc) and Partridge Coloured Hungarian layer (♀PHc)

Total egg production of PHc and MIc layers in the period of 6 months was significantly different (142 eggs/layer vs. 66 eggs/layer respectively, P<0.01). Birds laid the first egg either at the age of 23 weeks (PHc layers) or 24 weeks (MIc layers). Egg production of PHc and MIc is shown in Figure 13. EP% of PHc and MIc layers reached 50% at the age of 31 and

36 weeks, respectively. EP% of PHc rose sharply and reached a peak of 76% at the age of 37-38 weeks, then gradually declined to 50% after 5 months of lay. Production curves revealed that the egg yield of PHc layers is superior to that of MIc layers. The highest EP% of MIc layers were recorded at the age of 36 weeks (53%). By the age of the 48 weeks, it dropped below 30%.

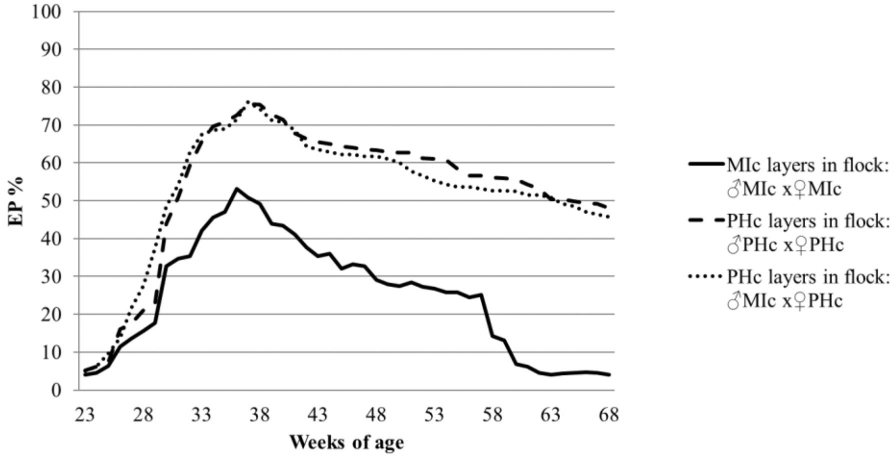

Figure 13. Egg production (%) of Mia (MIc) layers and Partridge Coloured Hungarian (PHc) layers in ♂MIc x ♀MIc, ♂PHc x ♀PHc and ♂MIc x ♀PHc flocks

Figure 14 demonstrates the incubation results of eggs collected from 37 to 38-week-old layers. Eggs produced in ♂MIc x ♀PHc flock had significantly higher fertility and hatchability than ♂PHc x ♀PHc and ♂MIc x ♀MIc flocks (96.94% vs. 96.26% vs. 94.53% for fertility and 85.19% vs. 82.92% vs. 71.26% for hatchability, respectively).

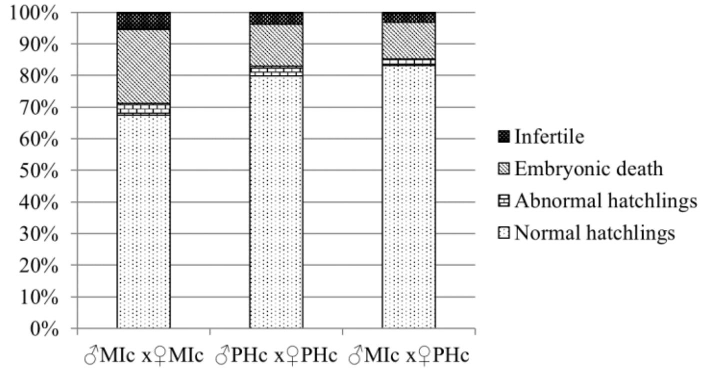

Figure 14. Incubation results of eggs produced by Mia (MIc) layers and Partridge Coloured Hungarian (PHc) layers in ♂MIc x ♀MIc, ♂PHc x ♀PHc and ♂MIc x ♀PHc flocks

Offspring of the three genotypes of chickens (MIc and PHc purebreds and ♂MIc x ♀PHc cross) were used for further studies of BW, FCR and H, by comparing rearing results of birds in semi intensive (si) and in three different conditions (si, sf and cf) for 12 weeks. The BW of male and female birds differed only at the age of 12 weeks (ANOVA test, $P<0.01$). si MIc x PHc shows significantly better performance than si MIc and si PHc in terms of BW (Table 22) and FCR (2.85 ± 0.18, 2.99 ± 0.18 and 3.06 ± 0.21kg/kg, respectively).

However, its carcass, breast and thigh percentages were significantly lower than si MIc and comparable to si PHc. The abdominal fat percent of si MIc x PHc was the lowest among 3 genotypes (Table 22). The effect of keeping system on BW was apparent at 8 and 12 weeks of age (Table 23). sf MIc x PHc and si MIc x PHc were significantly heavier than cf MIc x PHc. In crossbred males, no difference in BW between sf MIc x PHc and si MIc x PHc was found. Amongst female birds, sf MIc x PHc had significantly higher BW than si MIc x PHc.

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Table 22: Body weight and slaughter yield of 3 genotypes si MIc (offspring of the Mia purebred chicken), si PHc (offspring of Partridge Coloured Hungarian purebred chickens) and si MIc x PHc (offspring of the cross between Mia cockerel and Partridge Coloured Hungarian hens), heterosis (H) of si MIc x PHc reared in semi intensive (si) keeping system at Thuy Phuong Poultry Research Centre (POREC)

Traits		Male				Female			
		si MIc	si PHc	si MIc x PHc	H	si MIc	si PHc	si MIc x PHc	H
BW (g)	1 day old	37.4^{b} ±2.32	40.3^{a} ±3.05	40.2^{a} ±2.84	3.43	37.45^{b} ±2.63	40.8^{a} ±2.3	40.4^{a} ±2.51	3.25
	4 wks of age	284^{b} ±28.7	312^{a} ±33.2	317.5^{a} ±35.0	6.53	277.80^{b} ±34.44	306^{a} ±38.5	313^{a} ±31.7	7.26
	8 wks of age	663^{c} ±59.3	715^{b} ±68.4	802^{a} ±73.2	16.4	651.76^{c} ±79.24	710^{b} ±80.0	764^{a} ±80.3	12.3
	12 wks of age	1329^{c} ±61.3	1391^{b} ±76.7	1605^{a} ±89.4	18.0	1144.5^{c} ±72.02	1228^{b} ±88.0	1373^{a} ±90.2	15.8
Cw (%)		78.1^{a} ±0.26	76.6^{b} ±0.42	75.1^{c} ±0.72	-2.84	78.69^{a} ±0.15	76.5^{b} ±0.55	76.4^{b} ±0.51	-1.58
Tw (%)		21.0^{a} ±0.11	16.5^{b} ±0.10	16.6^{b} ±0.36	-11.2	19.63^{a} ±0.35	15.5^{c} ±0.35	16.2^{b} ±0.35	-7.69
Bw (%)		15.1^{a} ±0.30	13.1^{b} ±0.31	12.7^{b} ±0.32	-10.2	15.26^{a} ±0.18	12.8^{b} ±0.35	13.5^{b} ±0.84	-4.27
Abdominal fat (%)		1.68^{a} ±0.01	1.56^{b} ±0.02	1.36^{c} ±0.02		2.28^{a} ±0.03	2.26^{a} ±0.05	1.98^{b} ±0.02	

BW: body weight; Eviscerated carcass weight: Cw: Thigh weight; Bw: Breast weight; wks: weeks
$^{a, b, c}$: different superscript letters show significant differences ($P<0.05$) between groups calculated by ANOVA test

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Table 23. Comparing body weight (g) of offspring of the cross between Mia (MIc) cockerel and Partridge Coloured Hungarian (PHc) hens, in semi intensive (si), semi free range (sf) and complete free range (cf) keeping systems

Age	Male				Female			
	si MIc x PHc	sf MIc x PHc	cf MIc x PHc	Sig.	si MIc x PHc	sf MIc x PHc	cf MIc x PHc	Sig.
8 wks	802^{a} ±73.2	804^{a} ±63.3	752^{b} ±81.9	**	764^{b} ±80.3	803^{a} ±86.6	764^{b} ±74.1	*
12 wks	1605^{a} ±89.4	1606^{a} ±82.0	1495^{b} ±68.9	**	1373^{b} ±90.2	1453^{a} ±68.8	1325^{c} ±66.5	**

*Sig.: significant level calculated by ANOVA test, *: P<0.05, **: P<0.01*
wks: weeks
[a, b, c:] *different superscript letters show significant differences (P<0.05) between groups*

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The lowest FCR was obtained in cf MIc x PHc (2.59 ± 0.28kg/kg), which is significantly lower than the FCR of sf MIc x PHc (2.98 ± 0.25 kg/kg) and si MIc x PHc (2.85 ± 0.18 kg/kg). It appeared that BW had a positive, while FCR had a negative H (-5.90%), indicating the advantage of the si MIc x PHc upon the mean parental performance. About slaughtering yield, the negative H means the superiority of parental genotypes to their crossbreds.

While the size of free-range area in si and sf system might not affect BW of male birds in this study, it showed significant effect on the BW of females. Indigenous female chickens, which were given a large foraging area of approximately 30m²/bird yielded significantly higher BW with lower standard deviation than birds with small fenced running area of 5 birds/m^2 (Table 23).

Previous studies show the usefulness of local breeds' or ecotypes' crossing programs (NDEGWA et al., 2012; OKENO et al., 2013; NGENO et al., 2014). Our results are consistent with the theory of FAIRFULL (1990) and WILLIAMS et al. (2002) that the crossing of two indigenous chicken breeds of distant origin but marked in the same "indigenous and rare" category can be even more promising for genetic improvement even in production traits.

The high survival rate and EP% of pure PHc ascertained their potential to adapt in the tropics and subtropics, just like other old Hungarian poultry breeds studied in Vietnam (DONG XUAN et al., 2008). The use of local MIc as the sire and exotic PHc as the dam in cross is reasonable based on the EP% results of parents, BW and FCR of crossbreds. Crossed chickens from indigenous origin used in this study are better-growing than the ones reported for different extensive genotypes in the study of JATURASITHA

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et al. (2008), and their eviscerated carcass percentage is also higher than that of most slow growing chickens studied by FANATICO et al. (2008) and WANG et al. (2009).

Regarding the impact of keeping system in this study, the BW of birds reared without indoor housing area was the lowest amongst the studied groups. This result confirms the fact that complete free-range rearing without indoor housing area would reduce significantly BW of birds, and that an optimal indoor housing area in the rearing system of indigenous chickens is essential even in the tropics. Different effect of the size of free-range area on 12-week BW of male and female birds might be explained at least in two ways. (1) Indigenous female chickens are more sensitive to the size of free-range area and perform better in a rearing system with larger one. (2)

Early sexual maturity was observed as a characteristic feature of old Hungarian chicken breeds (SZALAY, 2015). Fighting habit for ranking of male birds even at early age might result in somewhat higher depression of average BW with higher standard deviation than among females in sf keeping system. These explanations, however, need further confirmation.

Through crossing, conserved chicken breeds such as PHc and MIc may find their way to get involved efficiently in sf farming, the most popular types of poultry keeping in rural areas of either Hungary (SZALAY et al., 2009) or Southeast Asian countries (BETT et al., 2014). Additionally, not only the improvement of MIc's productivity *in situ* and PHc' s utilisation *ex situ* can be achieved, but also enhanced and effective conservation basis of both purebreds is ensured, as proposed by DONG XUAN et al. (2008). Whether and to what extent the reverse cross (♂PHc x ♀MIc) affects the expression of studied traits might be the subject of additional experiments.

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But, since MIc has relatively low egg producing ability, this aspect may be of much less practical importance. Disease resistance and gustatory qualities of crossbred are suggested to be included in further assessments.

5.6. Crosses of Partridge Coloured Hungarian and 2 Bábolna Tetra's chicken lines

Factorial effect

Descriptive analyses of all the studied traits were summarized in Tables 24, 25, 26, 27, 28 and 29. ANOVA tests showed that genotype, gender and their interacting effect on body weight and feed conversion ratio was significant at 12 weeks of age. Genotype effect was obvious in all analyses of productive traits (BW, FCR, Cw, Bw, Tw, CW%, Bw%, Tw%, EP and Em) and some quality traits (a* and Ci of breast meat measured at 3 hours after cutting, Ew and ELe at 3 studied ages, EWi at 28 and 34 weeks of age, ESi at 34 and 40 weeks of age, ESt and ESs at 34 weeks of age, and egg shell colour at all studied age). The appearance of ♂ THc x PHc, ♀ THc x PHc, ♂ PHc x THc, ♀ PHc x THc, ♂ BHc x PHc, ♀ BHc x PHc, ♂ PHc x BHc and ♀ PHc x BHc were shown in Figures 15 and 16.

♂ PHc x THc

♀ PHc x THc

♂ THc x PHc

♀ THc x BHc

Figure 15. The appearance of crossbreds in the reciprocal crosses between Partridge Coloured Hungarian chicken (PHc) and Bábolna Tetra H dual purpose, father line (THc)

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♂ PHc x BHc

♀ PHc x BHc

♂ BHc x PHc

♀ BHc x BHc

Figure 16. The appearance of crossbreds in the reciprocal crosses between Partridge Coloured Hungarian chicken and Bábolna Harco, egg type, mother line (BHc)

The significant effect of layers' ages as well as interacting effect between layers' age and breed are observed while studying Ew, ELe, EWi, ESi, ESs, ESt, egg shell colour and ΔE between 28 and 34 weeks of age as well as 34 and 40 weeks of age. The effect of pens on studied traits, gender on survival rate and storing time of meat after slaughtering on breast meat colour are not significant.

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Liveability and productivity

Detailed results of the male and female birds' performance were presented in Tables 24 and 25, respectively. Survival rates recorded during the first 12 weeks of rearing in the crossbreds were relatively higher than in the purebreds. The highest and lowest values at the end of 12-week-rearing period were found in ♂ THc x PHc, ♀ THc x PHc and ♂ THc, respectively. Interestingly, ♀ THc has the highest survival rate amongst genotypes during laying. Male birds were heavier than female ones of the same genotype. Birds with THc genotype in the background (♂ THc, ♂ THc x PHc, ♂ PHc x THc, ♀ THc, ♀ THc x PHc and ♀ PHc x THc) were significantly heavier than other genotypes of similar genders. The offspring of purebred THc (♂ THc and ♀ THc) were the heaviest, followed by birds from the crosses in which THc was used as cockerels (♂ THc x PHc and ♀ THc x PHc). If comparing the BW of birds of the same gender, the lowest BW were obtained in ♂ PHc and ♀ PHc.

Nonetheless, the offspring of its crosses with purebred ♀ BHc (♂ PHc x BHc and ♀ PHc x BHc) were relatively heavier than that of purebred ♂ BHc and ♀ BHc. The FCR was highest in ♂ BHc and ♀ BHc, lowest in ♂ THc and ♀ THc, and not significantly different among other genotypes. The results of Cw, Bw and Tw were consistent with BW results. Interestingly, the highest Cw% and Bw% were found not only in ♂ THc, but also in ♂ PHc x THc. The highest Tw% belonged to ♂ THc and ♂ BHc.

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Table 24: Results of male birds' performance at 12 weeks of age in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Traits	♂ THc x PHc	♂ BHc x PHc	♂ PHc x THc	♂ PHc x BHc	♂ PHc	♂ THc	♂ BHc	Sig.
Live%	100^{a}	98.0^{ab}	95.3^{ab}	99.3^{a}	93.3^{b}	90.8^{b}	96.7^{ab}	**
	±0.000	±2.00	±5.03	±1.15	±4.62	±1.44	±3.72	
BW	2258^{b}	1661^{f}	2141^{c}	1728^{d}	1558^{g}	3199^{a}	1704de	**
(g)	±43.1	±8.84	±14.6	±3.72	±16.2	±3.07	±8.15	
FCR	3.27^{bc}	3.10^{bc}	3.17^{bc}	3.07^{bc}	3.47^{bc}	2.90^{c}	3.50^{a}	**
(kg/kg)	±0.058	±0.100	±0.208	±0.058	±0.208	±0.001	±0.100	
Cw	1594^{b}	1192^{cd}	1446^{bc}	1153^{cd}	1045^{d}	2301^{a}	1165^{cd}	**
(g)	±132	±27.1	±90.1	±57.9	±60.1	±271	±26.0	
Bw	389^{b}	262^{c}	350^{bc}	278^{bc}	240^{c}	604^{a}	267^{bc}	**
(g)	±44.5	±25.4	±21.1	±29.9	±14.4	±95.0	±8.22	
Tw	547^{b}	394^{cd}	491^{bc}	394^{cd}	351^{d}	804^{a}	410^{cd}	**
(g)	±48.0	±11.8	±29.9	±27.3	±21.6	±86.7	±4.55	
Cw	72.4^{bc}	71.8^{bc}	73.0^{ab}	72.1^{bc}	70.7^{c}	74.9^{a}	72.0^{bc}	**
(%)	±0.665	±0.695	±0.397	±0.634	±0.755	±1.30	±0.444	
Bw	17.6^{ab}	15.8^{b}	17.7^{ab}	17.4^{ab}	16.2^{b}	19.6^{a}	16.5^{b}	**
(%)	±0.748	±1.06	±0.232	±1.33	±0.267	±1.10	±0.346	
Tw	24.9^{bc}	23.7^{c}	24.8^{bc}	24.6^{bc}	23.7^{c}	26.2^{a}	25.3^{ab}	**
(%)	±0.467	±0.569	±0.151	±0.520	±0.334	±0.589	±0.229	

*Sig.: significant level; **: P<0.01, ANOVA test; *: P<0.05, ANOVA test; $^{a, b, c, d}$: different superscript letters show significant differences (P<0.05) between treatments in a row detected by post hoc Tukey HSD test; Live%: liveability, BW: body weight; FCR: feed conversion ration; Cw: evisvcerated carcass weight; Bw: breast weight; Tw: thigh weight; PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♂ THc x PHc: male offspring of THc male and PHc female; ♂ BHc x PHc: male offspring of BHc male and PHc female; ♂ PHc x THc: male offspring of PHc male and THc female; ♂ PHc x BHc: male offspring of PHc male and BHc female; ♂ PHc: male offspring of PHc male and female; ♂ THc: male offspring of THc male and female; ♂ BHc: male offspring of BHc male and female*

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Table 25: Results of female birds' performance investigated in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Traits	♀ THc x PHc	♀ BHc x PHc	♀ PHc x THc	♀ PHc x BHc	♀ PHc	♀ THc	♀ BHc	Sig.
Live%	100^{a}	98.7^{ab}	99.3^{ab}	99.3^{b}	96.0^{b}	97.5^{b}	91.3^{b}	**
(12 wks of age)	±0.001	±0.001	±0.667	±0.667	±2.66	±2.46	±0.379	
BW	1673^{b}	1194^{e}	1553^{c}	1240^{d}	1124^{f}	2411^{a}	1189^{de}	**
(g, 12 wks of age)	±38.4	±16.5	±0.928	±7.55	±8.87	±59.2	±5.01	
FCR	3.17^{b}	3.20^{bc}	3.10^{bc}	3.10^{bc}	3.30^{b}	2.20^{c}	4.83^{a}	**
(kg/kg)	±0.058	±0.001	±0.100	±0.100	±0.001	±0.500	±1.15	
Live%	90.4	88.3	92.6	92.4	94.0	96.8	91.4	ns
(49 wks of age)	±2.46	±8.31	±5.90	±1.03	±0.655	±3.26	±2.50	
Age at 1^{st} egg	144^{b}	165^{a}	145^{b}	147^{b}	151^{ab}	150^{ab}	145^{b}	**
(days)	±0.577	±4.36	±1.73	±3.79	±8.66	±10.1	±1.73	
EP	55.3^{ab}	48.5^{b}	42.4^{b}	53.7^{ab}	46.6^{b}	66.0^{a}	64.3^{a}	**
(%)	±6.77	±4.25	±9.26	±3.19	±1.51	±5.89	±2.03	
Em	6.72^{ab}	5.51^{b}	4.97^{b}	6.57^{ab}	5.14^{b}	7.97^{a}	8.29^{a}	**
(kg/layer)	±0.838	±0.546	±1.16	±0.400	±0.016	±0.857	±0.343	

*Sig.: significant level; **: P<0.01, ANOVA test; *: P<0.05, ANOVA test; $^{a, b, c, d}$: different superscript letters show significant differences (P<0.05) between treatments in a row detected by post hoc Tukey HSD test; Live%: liveability, BW: body weight; FCR: feed conversion ration; EP: egg production; Em: egg mass per layer;PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♀ THc x PHc: female offspring of THc male and PHc female; ♀ BHc x PHc: female offspring of BHc male and PHc female; ♀ PHc x THc: female offspring of PHc male and THc female; ♀ PHc x BHc: female offspring of PHc male and BHc female; ♀ PHc: female offspring of PHc male and female; ♀ THc: female offspring of THc male and female; ♀ BHc: female offspring of BHc male and female; wks: weeks*

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Most of studied female birds laid their 1st egg at the age of 21 weeks. The earliest and latest age at 1st egg was observed in ♀ THc x PHc and ♀ BH x PHc, respectively. The EP and Em of ♀ THc and ♀BHc were significantly higher than that of ♀ PHc, ♀ BHc x PHc and ♀ PHc x THc, but comparable to ♀THc x PHc and ♀ PHc x BHc. The EP over layers' age is shown in Figure 17. The EP of all genotypes rise sharply in the first month of egg production. It reaches 50% by the 26 weeks of age (apart from the EP of ♀ BHc x PHc) and the peak production by 32 weeks of age (apart from the EP of ♀ PHc x THc). Obviously, ♀ BHc and ♀THc have the most superior EP, followed by ♀ THc x PHc, ♀ PHc x BHc, ♀ BHc x PHc, ♀ PHc x PHc and ♀ PHc x THc.

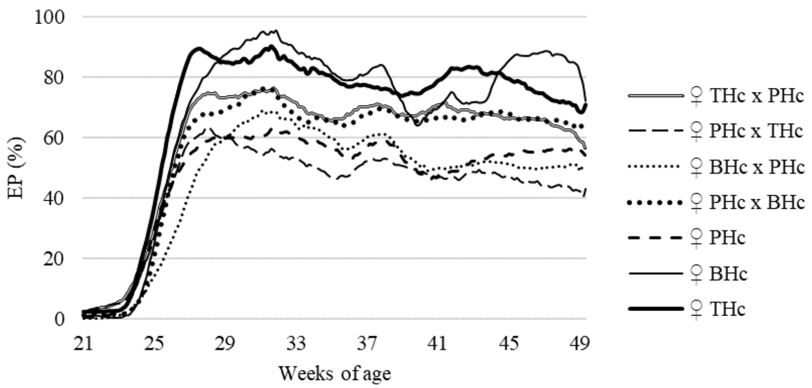

Figure 17. Egg production (EP) in percent of crossbred layers

(PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♀ THc x PHc: female offspring of THc male and PHc female; ♀ BHc x PHc: female offspring of BHc male and PHc female; ♀ PHc x THc: female offspring of PHc male and THc female; ♀ PHc x BHc: female offspring of PHc male and BHc female; ♀ PHc: female offspring of PHc male and female; ♀ THc: female offspring of THc male and female; ♀ BHc: female offspring of BHc male and female)

Breast meat colour

At 3 hours after cutting, the a* of ♂ PHc x BHc and ♂ PHc were significantly higher than that of ♂ THc x BHc, ♂ THc and ♂ BHc. The Ci value was highest in ♂ PHc, ♂ PHc x BHc and ♂ THc x PHc respectively. The L*, b*, Ci (except for ♂ BHc) measured at 24 hours after cutting were higher than that measured at 3 hours after cutting. The increases of a* measurement between 3 and 24 hours after cutting were found only in ♂ THc x PHc, ♂ BHc x PHc, ♂ PHc x THc and ♂ THc. In case of ♂ PHc x BHc, ♂ PHc and ♂ BHc, lower a* values are seen at 24 hours after cutting. Although no significant difference in ΔE of breast meat was obtained, it worth to note the highest one belongs to ♂ THc.

Table 26: Breast meat colour of 12-week-old birds measured at 3 and 24 hours after slaughtering in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Traits		♂ THc x PHc	♂ BHc x PHc	♂ PHc x THc	♂ PHc x BHc	♂ PHc	♂ THc	♂ BHc	Sig.
3 hours	L*	51.8 ±2.30	49.0 ±2.24	49.3 ±0.818	51.1 ±0.794	52.7 ±1.37	48.9 ±1.12	52.2 ±1.46	ns
	a*	0.739^{c} ±0.986	2.59^{abc} ±1.01	1.95^{abc} ±0.732	3.71^{a} ±0.656	3.26^{ab} ±0.772	1.11^{bc} ±1.11	0.912^{bc} ±0.702	**
	b*	6.52 ±0.582	7.55 ±0.826	6.28 ±0.328	7.64 ±0.625	7.97 ±1.70	6.16 ±0.254	8.03 ±0.345	ns
	Ci	44.5^{a} ±1.55	38.8^{b} ±2.55	41.1^{ab} ±0.335	39.8^{ab} ±0.555	41.4^{ab} ±2.17	41.7^{ab} ±2.21	43.3^{ab} ±2.09	*
24 hours	L*	57.4 ±3.74	53.2 ±0.848	52.7 ±0.455	53.1 ±2.72	56.0 ±3.91	59.2 ±7.95	54.2 ±2.85	ns
	a*	1.06 ±1.07	2.80 ±1.03	2.90 ±0.741	2.27 ±0.474	2.29 ±2.96	2.32 ±1.16	0.543 ±0.84	ns
	b*	9.24 ±3.05	11.4 ±2.81	8.50 ±2.63	9.20 ±1.41	7.81 ±3.04	11.7 ±5.15	11.3 ±2.63	ns
	Ci	47.1 ±5.78	38.9 ±4.04	41.2 ±3.16	41.7 ±4.23	45.9 ±3.97	45.1 ±6.96	42.4 ±2.85	ns
ΔE between 3-24 hours		6.80 ±5.74	6.26 ±2.10	4.65 ±1.76	3.61 ±2.60	5.09 ±1.58	13.1 ±7.97	5.04 ±2.52	ns

*Sig.: significant level; **: P<0.01, ANOVA test; *: P<0.05, ANOVA test, ns: not significant; $^{a, b, c, d}$: different superscript letters show significant differences (P<0.05) between treatments in a row detected by post hoc Tukey HSD test; L*: lightness; a*: redness; b*: yellowness; Ci: colour index; ΔE: total colour change; PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♂ THc x PHc: male offspring of THc male and PHc female; ♂ BHc x PHc: male offspring of BHc male and PHc female; ♂ PHc x THc: male offspring of PHc male and THc female; ♂ PHc x BHc: male offspring of PHc male and BHc female; ♂ PHc: male offspring of PHc male and female; ♂ THc: male offspring of THc male and female; ♂ BHc: male offspring of BHc male and female*

Egg quality

While Ew, ELe and EWi of most genotypes increase over time, the ELe of ♀ PHc and EWi of ♀ BHc were higher at the age of 34 weeks than 28 and 40 weeks. Ew of crossbreds were comparable to purebred ♀BHc and THc at 28 weeks of age. The calculation of ESi revealed that it was highest at the age of 34 weeks in most genotypes other than ♀ PHc. Instead, the highest and lowest ESi of ♀ PHc was seen at age of 34 and 40 weeks, respectively. Most of calculated ESi values were higher than 76. Only the ESi of ♀ PHc x THc at the age of 28 and 40 weeks, the ESi of ♀ PHc at the age of 34 weeks were lower than 76%. Furthermore, the ESs and ESt of all genotypes are significantly higher at the age of 34 and 40 weeks. The ♀ THc and ♀ BHc seem to have the most superior egg quality among genotypes. Despite this overall judgement, the strongest and thickest egg shell were found in ♀ BHc x PHc and ♀ PHc x BHc.

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Table 27: Quality traits of eggs from 28, 34 and 40-week-old layers investigated in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Age	Traits	♀ THc x PHc	♀ BHc x PHc	♀ PHc x THc	♀ PHc x BHc	♀ PHc	♀ THc	♀ BHc	Sig.
28 wks	Ew	50.6^{a}	51.9^{a}	47.5^{b}	50.4^{a}	46.0^{b}	51.2^{a}	51.8^{a}	**
	(g)	±0.187	±0.047	±1.67	±0.847	±0.466	±1.86	±0.566	
	ELe	5.56^{a}	5.49^{ab}	5.50^{ab}	5.48^{ab}	5.36^{b}	5.51^{ab}	5.49^{ab}	*
	(cm)	±0.012	±0.003	±0.122	±0.044	±0.021	±0.087	±0.017	
	EWi	4.21^{a}	4.23^{a}	4.12^{b}	4.21^{a}	4.09^{b}	4.23^{a}	4.24^{a}	**
	(cm)	±0.007	±0.001	±0.016	±0.024	±0.050	±0.034	±0.040	
	ESi	75.7	77.1	74.9	76.9	76.3	76.8	77.3	ns
	(%)	±0.297	±0.035	±1.37	±1.05	±1.24	±0.587	±0.503	
	ESs	4.07	4.48	4.32	4.51	4.14	4.33	4.12	ns
	(kg/cm^2)	±0.297	±0.264	±0.118	±0.064	±0.253	±0.266	±0.330	
	ESt	0.280	0.331	0.290	0.315	0.299	0.278	0.308	ns
	(mm)	±0.010	±0.011	±0.012	±0.016	±0.024	±0.037	±0.005	
34 wks	Ew	55.4^{bcd}	57.0^{b}	52.7^{d}	58.1^{b}	53.5^{cd}	56.1^{bc}	61.3^{a}	**
	(g)	±0.622	±1.06	±0.700	±0.056	±1.59	±1.41	±0.444	
	ELe	5.64^{abc}	5.61^{bc}	5.61^{bc}	5.54^{c}	5.70^{ab}	5.60^{bc}	5.74^{a}	**
	(cm)	±0.025	±0.055	±0.005	±0.020	±0.070	±0.053	±0.036	
	EWi	4.40^{ab}	4.39^{ab}	4.29^{bc}	4.36^{ab}	4.23^{c}	4.35^{b}	4.48^{a}	**
	(cm)	±0.035	±0.050	±0.073	±0.030	±0.045	±0.031	±0.010	
	ESi	78.0^{ab}	78.3^{a}	76.6^{b}	78.7^{a}	74.1^{c}	77.6^{ab}	78.1^{ab}	**
	(%)	±0.275	±0.124	±1.38	±0.257	±0.121	±0.186	±0.313	
	ESs	4.23^{c}	4.96^{ab}	4.11^{c}	5.07^{a}	4.27^{c}	4.49^{c}	4.51^{bc}	**
	(kg/cm^2)	±0.029	±0.203	±0.299	±0.036	±0.023	±0.151	±0.154	
	ESt	0.374^{b}	0.397^{ab}	0.351^{b}	0.488^{a}	0.405^{ab}	0.386^{b}	0.389^{b}	**
	(mm)	±0.002	±0.008	±0.008	±0.084	±0.028	±0.009	±0.004	

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40 wks	Ew	57.6^{b}	59.8^{ab}	58.2^{b}	58.7^{b}	54.2^{c}	59.4^{ab}	61.7^{a}	**
	(g)	±0.624	±0.516	±0.059	±1.68	±0.463	±0.273	±1.48	
	ELe	5.69^{bc}	5.72^{abc}	5.85^{a}	5.67^{bc}	5.65^{c}	5.80^{ab}	5.78^{abc}	**
	(cm)	±0.035	±0.045	±0.045	±0.045	±0.015	±0.037	±0.105	
	EWi	4.40	4.43	4.36	4.40	4.38	4.43	4.46	ns
	(cm)	±0.030	±0.010	±0.010	±0.065	±0.055	±0.033	±0.010	
	ESi	77.4^{a}	77.5^{a}	74.6^{b}	77.6^{a}	77.5^{a}	76.4^{ab}	77.2^{a}	**
	(%)	±0.051	±0.785	±0.745	±0.531	±1.18	±1.06	±1.23	
	ESs	4.15	4.34	4.30	4.62	4.42	4.46	4.46	ns
	(kg/cm^2)	±0.189	±0.117	±0.232	±0.063	±0.086	±0.495	±0.045	
	ESt	0.313	0.319	0.334	0.345	0.329	0.332	0.338	ns
	(mm)	±0.009	±0.010	±0.019	±0.016	±0.003	±0.022	±0.001	

*Sig.: significant level; **: P<0.01, ANOVA test; *: P<0.05, ANOVA test, ns: not significant; $^{a, b, c, d}$: different superscript letters show significant differences (P<0.05) between treatments in a row detected by post hoc Tukey HSD test; PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♀ THc x PHc: female offspring of THc male and PHc female; ♀ BHc x PHc: female offspring of BHc male and PHc female; ♀ PHc x THc: female offspring of PHc male and THc female; ♀ PHc x BHc: female offspring of PHc male and BHc female; ♀ PHc: female offspring of PHc male and female; ♀ THc: female offspring of THc male and female; ♀ BHc: female offspring of BHc male and female; wks: weeks*

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Egg shell colour

The analyses of shell colour characteristics showed that all the highest values were detected at 34 weeks of age. While the highest L*, Ci and lowest a*, b*, were observed in ♀ PHc, the opposite was true for ♀ BHc which owned the lowest L*, Ci and highest a* and b*. The shell colour attributes of eggs from 34 and 40-week-old crossbreds vary greatly. In which, the L* of 34-week-old ♀ BTc x PHc and ♀ PHc x THc, the a* of 34 and 40-week-old ♀ BHc x PHc were significantly higher than that of other crossbreds with the same age. Additionally, the eggs from ♀ BHc x PHc had the lowest Ci compare to other crossbred genotypes. Meanwhile, the highest Ci values were found in ♀ THc x PHc at 28 weeks of age, in ♀ PHc x THc at 34 and 40 weeks of age. Between 28 and 34 weeks of age, ΔE calculated in ♀ BHc x PHc and ♀PHc x BHc egg shell was significantly higher than in others. Between 34 and 40 weeks of age, the highest and lowest ΔE were obtained in ♀ PHc and ♀ THc, ♀ THc x PHc, respectively.

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Table 28: Shell colour of eggs from 28, 34 and 40-week-old layers investigated in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Age	Traits	♀ THc x PHc	♀ BHc x PHc	♀ PHc x THc	♀ PHc x BHc	♀ PHc	♀ THc	♀ BHc	Sig.
28 wks	L*	76.3^{a} ±0.088	75.5^{ab} ±0.150	75.8^{ab} ±0.860	74.9^{ab} ±0.417	76.7^{a} ±1.06	73.9^{bc} ±1.21	71.9^{c} ±0.499	**
	a*	5.81^{bc} ±0.158	6.23^{bc} ±0.021	5.08^{bc} ±0.631	6.64^{ab} ±0.647	4.36^{c} ±1.36	6.74^{ab} ±0.395	8.37^{a} ±0.614	**
	b*	23.9^{bcd} ±0.098	25.5^{b} ±0.659	24.7^{bcd} ±0.534	23.7^{cd} ±0.816	23.2^{d} ±0.788	25.3^{bc} ±0.626	28.0^{a} ±0.124	**
	Ci	46.6^{ab} ±0.168	43.8^{b} ±0.830	46.0^{ab} ±2.03	44.5^{ab} ±0.248	49.2^{a} ±3.20	41.9^{b} ±2.23	35.5^{c} ±1.24	**
34 wks	L*	73.4^{b} ±0.710	71.5^{c} ±0.436	74.6^{b} ±0.596	71.4^{c} ±0.947	77.2^{a} ±1.05	74.5^{b} ±0.161	70.0^{c} ±0.154	**
	a*	7.35^{b} ±0.342	9.06^{a} ±0.137	5.92^{c} ±0.216	8.57^{a} ±0.517	4.54^{d} ±0.381	6.16^{c} ±0.736	9.64^{a} ±0.012	**
	b*	27.1^{ab} ±0.326	27.1^{ab} ±0.104	26.3^{b} ±0.188	26.6^{b} ±0.786	23.2^{c} ±0.161	25.6^{b} ±1.53	28.6^{a} ±0.419	**
	Ci	38.9^{cd} 0.726	35.3^{e} 0.470	42.3^{bc} 1.00	36.2^{de} 0.677	49.5^{a} 1.59	42.8^{b} 2.43	31.8^{f} 0.56	**
40 wks	L*	73.8^{ab} ±0.255	72.4^{b} ±0.096	72.8^{ab} ±1.51	73.4^{ab} ±0.481	73.6^{ab} ±0.162	74.5^{a} ±0.409	69.8^{c} ±0.799	**
	a*	6.43^{c} ±0.171	7.53^{b} ±0.163	5.82^{d} ±0.317	6.63^{c} ±0.066	5.05^{e} ±0.063	5.12^{e} ±0.127	8.37^{a} ±0.148	**
	b*	26.0^{abc} ±0.374	26.3^{ab} ±0.248	24.7^{cd} ±0.310	25.5^{bcd} ±0.158	24.1^{d} ±0.698	25.2^{bcd} ±0.247	27.4^{a} ±1.06	**
	Ci	41.3^{ab} ±0.458	38.6^{b} ±0.011	42.4^{a} ±2.14	41.3^{ab} ±0.390	44.5^{a} ±0.923	44.2^{a} ±0.783	34.1^{c} ±2.01	**

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ΔE between:	28-34 wks	4.66^{ab} ±0.265	5.23^{a} ±0.714	2.38^{bc} ±1.50	4.93^{a} ±0.337	2.12^{c} ±1.42	1.39^{c} ±0.621	2.36^{bc} ±0.533	**
	28-40 wks	3.33 ±0.420	3.57 ±0.207	3.25 ±2.29	2.36 ±0.535	3.40 ±1.07	1.83 ±0.505	2.34 ±0.149	ns
	34-40 wks	1.69^{b} ±0.360	2.04^{ab} ±0.324	2.50^{ab} ±0.544	3.09^{ab} ±0.352	3.73^{a} ±1.42	1.50^{b} ±0.766	1.89^{ab} ±0.443	*

*Sig.: significant level; **: P<0.01, ANOVA test; *: P<0.05, ANOVA test, ns: not significant; $^{a, b, c, d, e, f}$: different superscript letters show significant differences (P<0.05) between treatments in a row detected by post hoc Tukey HSD test; L*: lightness; a*: redness; b*: yellowness; Ci: colour index; ΔE: total colour change; PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♀ THc x PHc: female offspring of THc male and PHc female; ♀ BHc x PHc: female offspring of BHc male and PHc female; ♀ PHc x THc: female offspring of PHc male and THc female; ♀ PHc x BHc: female offspring of PHc male and BHc female; ♀ PHc: female offspring of PHc male and female; ♀ THc: female offspring of THc male and female; ♀ BHc: female offspring of BHc male and female; wks: weeks*

Direct heterosis and reciprocal effect

Table 29 represents the H calculated for mean and RE of studied crossbreds. The range of H was narrowest and largest in ♂ THc x ♀ PHc and ♂ PHc x ♀ BHc, respectively. The ♂ PHc x ♀ BHc exhibited more positive H than other crossbred genotypes with the highest of 9.79 calculated for Bw. Its H was only negative for FCR and EP. In addition to FCR and EP, the H of ♂ BHc x ♀ PHc was also negative for Bw, Tw and Ew at 34-week-old. In case of ♂ THc x ♀ PHc and ♂ PHc x ♀ THc, the H values were mainly negative except for FCR, Cw% and Ew. Ew at 40-week-old was the only trait from which positive H could be found in all 4 crossbred genotypes. The results of RE revealed that ♂ THc x ♀ PHc performed better than ♂ PHc x ♀ THc in term of BW, Cw, Bw, Tw, Tw%, EP and Ew. And, ♂ BHc x ♀ PHc performed better than ♂ PHc x ♀ BHc only in term of Ew at 28 and 40 weeks of age. Moreover, both negative H and positive RE values were obtained in FCR measurements of crossbred genotypes in which PHc was used as cockerel. Apparently, the most beneficial effect of crossing on each genotype was achieved in Cw (♂ BHc x ♀ PHc), Bw (♂ PHc x ♀ BHc) and Ew (♂ THc x ♀ PHc and ♂ PHc x ♀ THc).

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Table 29: Heterosis (%) and reciprocal effect calculated for body weight (BW), feed conversion ratio (FCR) and eviscerated carcass (Cw), breast (Bw) and thigh (Tw) weight, egg production (EP) and egg weight (Ew) of crossbreds investigated in study 6: Crosses of PHc and 2 commercial chicken lines (THc and BHc)

Traits	Heterosis (H)				Reciprocal effect (RE)	
	♂ THc x ♀ PHc	♂ PHc x ♀ THc	♂ BH x ♀ PHc	♂ PHc x ♀ BHc	♂ THc x ♀ PHc – ♂ PHc x ♀ THc	♂ BHc x ♀ PHc – ♂ PHc x ♀ BHc
BW of males (g, 12 wks of age)	-5.09	-10.0	+1.81	+5.97	+117	-67.9
BW of females (g, 12 wks of age)	-5.35	-12.2	+3.20	+7.24	+120	-46.7
FCR of males (kg/kg, 12 wks of age)	+2.62	-0.524	-11.0	-12.0	+0.100	+0.033
FCR of females (kg/kg, 12 wks of age)	+15.2	+12.7	-21.3	-23.8	+0.067	+0.100
Cw (g, 12 wks of age)	-4.71	-13.6	+7.85	+4.37	+149	+38.5
Bw (g, 12 wks of age)	-7.90	-17.1	+3.48	+9.79	+39.0	-16.0
Tw (g, 12 wks of age)	-5.17	-14.9	+3.70	+3.71	+56.0	-0.028
Cw (%,12 wks of age)	-0.527	+0.190	+0.565	+0.979	-0.522	-0.295
Bw (%,12 wks of age)	-1.65	-1.56	-3.65	+6.11	-0.017	-1.60
Tw (%,12 wks of age)	-0.37	-0.63	-3.20	+0.386	+0.065	-0.879
EP (%)	-1.81	-24.7	-12.5	-3.13	+12.9	-5.19
Ew at 28 wks of age (g)	+3.96	-2.41	+6.07	+3.07	+3.10	+1.47
Ew at 34 wks of age (g)	+1.07	-3.86	-0.636	+1.25	+2.70	-1.09
Ew at 40 wks of age (g)	+1.41	+2.46	+3.16	+1.35	-0.595	+1.05

PHc: Partridge Coloured Hungarian chickens; THc: Bábolna Tetra H dual purpose, father line; BHc: Bábolna Harco egg type, mother line; ♂ THc x PHc, f THc x PHc: offspring of THc male and PHc female; ♂ BHc x PHc, ♀ BHc x PHc: offspring of BHc male and PHc female; ♂ PHc x THc, ♀ PHc x THc: offspring of PHc male and THc female; ♂ PHc x BHc, ♀ PHc x BHc: offspring of PHc male and BHc female; ♂ PHc x PHc, ♀ PHc x PHc:offspring of PHc male and female wks: weeks

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Growing demand for good quality poultry products, meat and egg from extensive systems has been confirmed by various scientists (FANATICO et al., 2005, SMITH et al., 2012; WALLEY et al., 2015). Basically, these products (e.g. Label Rouge chickens in France) are created exclusively by crossing native chicken breeds and fast-growing lines (SMITH et al., 2012, FRANCO et al., 2012). Comparing to Label Rouge chickens, all studied PH crossbreds have lower FCR. The mBTxPH and mPHxBT even have heavier BW and Cw at the age of 12 weeks than Label Rouge chickens (YOUSSAO et al., 2009, YOUSSAO et al., 2012). Although compared to THc and BHc, PHc and their crossbreds show lower growth, dressing percentage and egg production, their meat and egg quality characteristics may be valued by modern consumers and referred over the commercial chicken in terms of overall acceptability.

Among meat quality traits, colour is perhaps one of the most important factors that influences consumer decision making (FLETCHER, 2002; IMRAN et al., 2014; PARROTT et al., 2016). The breast meat of ♂ PHc and ♂ PHc x BHc have high a* and low ΔE. The high a* value of breast meat might be due to high total haem and myoglobin content (CASTELLINI et al., 2002) or the result of natural genetics (BERRI et al., 2005). The breast meat of ♂ BHc x PHc is the darkest among genotypes. From a marketing perspective, most consumers believe that dark meat is superior in flavour and healthiness (WIDEMAN et al., 2016).

According to UNECE standard (2010), the eggs of studied genotypes collected at 34 and 40 weeks of age are medium-sized (Ew ≥ 53 and < 63). If adapting egg classification system reported by DUMAN et al. (2016), the studied eggs belong to either standard (ESi ranges from 72 to 76) or round categories (ESi > 76). Moreover, high ESs obtained in ♀ BHc x PHc and ♀ PHc x BHc may benefit both physical, pathogenic defence from the external environment and embryo development by providing a source of nutrients (HUNTON, 2005). Beside egg quality traits, egg shell pigmentation is worth mentioning too. CAVERO et al. (2012) stated that shell colour is closely associated with consumers' attitudes and market demands. Eggs collected in this study are mostly light brown. Egg shell is the lightest in PHc and the darkest in BHc. Among crossbreds, the darkest egg shell is found in ♂ BHc x ♀ PHc. Interestingly, studied hens tend to lay lighter eggs at the start and end of the laying cycle when the EP is low, similar to the report of ODABASI et al. (2007). Thus, egg shell pigmentation may be used as the indicator of lay performance.

The higher the heterosis, the smaller the degree of genetic resemblance between parental populations and the magnitude of heterosis is expected to be proportional to the degree of heterozygosity (SHERIDAN, 1981). Strong negative heterosis effects obtained in BW, Cw, Bw and Tw of ♂ THc x ♀ PHc and ♂ PHc x ♀ THc could be attributed to the greater genetic distance between PHc and THc. It can be also explained by the high difference of growth and conformation performances existing between the two genotypes. Considering the RE results, both paternal effect of PHc and THc as well as maternal effects of BHc are recognisable.

From the overall performance of ♂ BHc x ♀ PHc and ♂ PHc x ♀ BHc (better Bw, FCR, Cw, Bw Tw and Ew than that of PHc), the study confirms the conclusion of KAMEL (2016) and KHAWAJA et al. (2016) that crossbreds between native and commercial genotypes may have higher rate of growth, better feed conversion and greater slaughter yield than native breeds. Through crossing, characteristics that are advantageous for promoting such as dark meat and high egg shell strength also appear in the

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crossbreds. Since the interest in using local poultry breed in production has spread through Europe (MAGDELAINE et al., 2008), such crossbreds may also fit in practice.

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6. CONCLUSIONS

6.1. Population study of 14 old Hungarian poultry breeds

Based on the population study, it can be concluded that number of breeding stocks (n), effective population size (N_e) and inbreeding rate (ΔF) together are good indicators for a genetic conservation programme. It is important to monitor these indicators generation by generation. The high n, as well as sustainable subsidies are essential to eliminate any risk of dramatic decreases in N_e, which assures the safe conservation programme of a breed. A conservation strategy to minimize ΔF by maximising N_e and increasing N_m/N_f is recommended. Based on effectiveness and reliability, this study would promote the use of those indices for the Hungarian poultry conservation programmes as a model in practice.

6.2. Egg production study of 7 indigenous Hungarian chicken breeds

Since the WHc and YHc breeds showed consistently higher egg production than the others, these breeds would be preferred for free range extensive and ecology-oriented farming systems. In this study, we also found that most of the traditional Hungarian hens, being hatched in spring, produced a high number of eggs from March to May, whereas the opposite was true in the beginning, between December and February and at the end of their egg production cycle. The study provided information on egg production pattern of traditional chicken breeds. These results may help to improve the utilization and involvement of not only the Hungarian chicken breeds in family farming, but other sustainable agricultural production systems too.

DOI: 10.15477/SZE.WAMDI.2019.003

6.3. Adaptation study of Partridge Coloured Hungarian chicken in the subtropics

The high survival rate, overall productivity and reproductive ability of the PHc flock in Vietnam confirmed the adaptation potential of PHc to subtropical climates. As compared with parallel results in the continental climate of Hungary, higher number of eggs and higher total egg mass, alongside with considerably high fertility and hatchability of layers could outweigh their reduced egg size in the subtropics. It is recommended to establish and maintain PHc breeding stocks in subtropical regions. By the proposed agro-ecological way, PHc can efficiently be protected *ex situ*.

6.4. Crosses of Partridge Coloured Hungarian and a natively different Hungarian chicken breed

Overall, the use of PHc and WTc as parents for crossings may provide an advantage with regards to BW and FCR traits in the offspring. The higher degree of heterozygosity of the crossed offspring compared to their parents is mostly the reason for the observed heterosis. Thus, it is reasonable to state that using two Hungarian chicken breeds marked in the same category “indigenous and rare” possess certain potential for genetic improvement by crossing without making a compromise in product quality of the offspring. Crossing therefore can be considered as an additional tool for conservation by utilization and production of highly endangered, low producing breeds.

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6.5. Crosses of Partridge Coloured Hungarian and an old chicken breed of distant origin

Heterosis, positive for body weight and negative for feed conversion ratio, indicated that PHc – showing good adaptability to the subtropics of Vietnam – crossed with an indigenous Vietnamese breed of distant origin may offer a great potential for genetic improvement. By this way, both PHc and MIc, kept under genetic conservation programmes can be involved in traditional production systems in Vietnamese underprivileged areas.

6.6. Crosses of Partridge Coloured Hungarian and 2 Bábolna Tetra's chicken lines

The study confirms that crossbreds between PHc and THc may have higher rate of growth, better feed conversion and greater slaughter yield than PHc. Through such crossings however, unique characteristics of PHc that are advantageous for promotion such as dark meat and high egg shell strength apparently inherited in the crossbreds. Based on the results of this study, the crossbreds of PHc as paternal and BHc as maternal line is recommended for practical production.

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7. NEW SCIENTIFIC RESULTS

[1] Comparison of breed specific egg production patterns of all seven Hungarian indigenous chicken breeds revealed, that egg production was consistently high in Yellow Hungarian chicken (0.493 eggs/hen/day) and White Hungarian chicken (0.468 eggs/hen/day). Meanwhile, Partridge Coloured Hungarian chicken could reach 0.490 eggs/hen/day. Transylvanian Naked Neck chickens can produce higher amount of eggs in the 2^{nd} lay then in the 1^{st} lay.

[2] Excellent adaptability of Partridge Coloured Hungarian chicken was scientifically proved in subtropical regions of Vietnam, which was realised by production traits (12-week body weight: 1.1kg to 1.4kg; egg production: 111 eggs/hen/7 months; peak of egg production: 70%; hatchability: 85%; mortality: 5%). It was verified that the breed can respond well to the challenge of climatic changes in continental climate, even as a crossing partner.

[3] Heterosis in productive traits was clearly demonstrated in crosses of the Partridge Coloured Hungarian chicken with a Transylvanian Naked Neck and the Vietnamese Mia chicken breed. In the cross of Partridge Coloured Hungarian chicken and Mia chicken, the average body weight of the offspring at 12 weeks is 1.3kg (female) and 1.6kg (male), and the eviscerated carcass percentage is approximately 75%.

[4] High performance of crossbred offspring was proven for reciprocal crosses of Partridge Coloured Hungarian chicken and commercial breeding lines (Bábolna Tetra H and Bábolna Harco). At 12 weeks, crossbreds of Partridge Coloured Hungarian chicken weighed approximately 1.6-2.2kg in the crosses with Bábolna Tetra H father line, and 1.2-1.6kg in the crosses with Bábolna Harco mother line. Feed conversion rate of both male and female offspring was below 3.3kg/kg and 3.2kg/kg, and eviscerated carcass percentage was about 72%. Their average egg production of crossbreds reached 53%.

[5] Solid heterotic effect in meat and egg production was demonstrated in reciprocal crosses of Partridge Coloured Hungarian chicken and egg type Bábolna Harco, mother line in such quantitative characteristics as growth (+1.81% to +7.27% for body weight, -23.8% to -11.0% for feed conversion rate and +0.565% to +0.979% for carcass percentage. Their breast meat's colour index was below 47, while egg shell strength and egg shell thickness were higher than 4.3kg/cm^2 and 0.3mm.

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