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# Polydactylism In Muscovy Ducks (*Cairina moschata*): Inheritance And Types Of Polydactyly

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## Abstract

Polydactyly is one of the most common congenital limb dysplasia frequently observed in farm animals and varies in expressivity. Herein, a preliminary investigation on inheritance and types of polydactyly in one hundred and four (104) ducklings produced by seven (7) mating groups (MGs) of different genotypes were reported. These ducklings were produced from non descript random bred population of Muscovy ducks in the Netherlands and data generated were analysed with descriptive (percentage and bar chart) and inferential statistics{Chi-square ($\chi^2$)}. The results indicated that irrespective of the genotypes of the parents, polydactyl gene (*Po*) had incomplete dominance and penetrance in the ducklings; however, the observed frequencies of polydactyly was not significantly (P>0.05) different from the expected proportions in all MGs. Further analysis of expressivity of the gene revealed prevalence of bilateral expression (97.18%) compared to the unilateral incidence (2.82%). The phenotypic expression of the mutant gene was classified into sixteen (16) distinct types and about one-third (31.82%) of polydactyl ducklings expressed type 5 polydactyly. In addition, dosage effect of *Po* and twin polyphalangeal($Po^{TP}$) genes exerted influence on incidence of polydactylism and observed polydactyly types. The highest number of polydactyly type was expressed by progenies of homozygous polydactyl parents. Conversely, $Po^{TP}$gene was antagonistic to the expression of polydactyly and the incidence of polydactylysim was highest among ducklings of non-twin polyphalangeal parents.

**Key word:** Bilateral expression, incomplete penetrance, Polydactyl gene, Polydactyly types, Twin polyphalangeal gene.

## Introduction

All species have specified number, length and orientation of digits on the limbs controlled by the genes. However, anomaly or deviation from the standard form is not uncommon. Congenital malformations of the limbs are among the most frequent congenital anomalies found in humans and animals and they preferentially affect the distal part (Leipold and Dennis, 1987; Talamillo *et al.*, 2005). Malformations of the extremities or parts of them varied in their manifestations ranging from the absence of a single structure to partial or complete absence of the limbs (Lallo *et al.*, 2001). Developmental 'disorder' review reports are comparatively scarce in the veterinary literature (Spiers *et al*., 2010) probably due to the multifactorial etiologic nature of such anomalies (Lanteri *et al*., 2012). Nevertheless, in-born limb deformities such as adactyly, abrachia, tibia hemimelia (Lallo *et al*., 2001; Mosbah *et al*., 2012), polydactyly (Sadan, 2017; Oguntunji, 2018) among others have been reported in farm animals.

Polydactyly is one of the most commonly observed congenital limb malformations and ciliopathies. This abnormality is characterized with additional digits in fingers or toes and there are reports of its association with dozens of genes and complicateddiseases (Faust *et al*., 2015). It constitutes the highest proportion among the congenital limb defects in various epidemiological surveys, but its regulation mechanism has not been well understood (Malik, 2014). Among avian species, polydactylyl has been widely reported in chickens (Zhang *et al.* 2016; Lange and Mueller, 2017), and wild birds (Albers *et al*., 2001; Sakai *et al*., 2006) while literature is sparse on other domesticated birds. The reports of pioneer studies on this congenital malformation in domestic chickens indicated that the gene controlling its expression is autosomal dominant and had incomplete penetrance because some individuals carrying the gene failed to express it (Punnet and Pease, 1929, Warren, 1944; Landaeur, 1948).

At present, empirical reports on genetic basis of inheritance, penetrance and expressivity of this mutant trait in ducks are not available. Therefore, the assertion of the low penetrance of the gene as the reason for its low frequency in ducks (Oguntunji, 2018) is subject to confirmation under controlled experiment. Such confirmatory studies are imperative due to the conflict of reports on genetic basis of its inheritance and the fact that inheritance pattern of similar traits within and between species may differ.

For example, earlier researchers (Punnet and Pease, 1929; Warren, 1944) attributed inheritance of polydactyly to autosomal dominant gene with low penetrance in chickens; while of recent, Langer and Mueller (2017) reported that the trait is controlled by epistatic action of gene (Robb and Delany, 2012) and with full penetrance in chickens (Robb and Delany, 2012; Langel and Muller, 2017). Similarly, autosomal recessive gene has been reported controlling inheritance of syndactyl polydactylism in Japanese quail (*Coturnix japonica*) Tsudzuki *et al.* (1998).While literature are abundant on its incidence, inheritance and expressivity in domestic chicken and some livestock, related studies on duck and waterfowl in general are scanty. In view of the foregoing, the present study reported a preliminary investigation on the inheritance of polydactyly and expressed polydactyly types in Muscovy duck. This is to further understand the inheritance pattern of polydactyl gene and its types in Muscovy duck.

## Materials and Methods

### *Study area*

The study was conducted in a private farmin Ridderkerk, the Netherlands and the coordinates of the study area is $4^0$ 34' 33.9"E, $51^0$53'52.8"N.

### *Breeding stock*

Adult seven (7) males and seven (7) female Muscovy ducks of above 10 months of age served as the parent stocks. The breeding stocks were were progenies offlocks of random-bred non-descript Muscovy ducklings brought from Suriname, South America to Netherlands and have multiplied over years through uncontrolled breeding.

The genotypes of the breeding stocks in respect of polydactyl (*Po*) gene and its variants; single polyphalangyl ($Po^{SP}$) and twin polyphalangyl ($Po^{TP}$) genes are presented in Table 1.

**Table 1.** Genotypes and gene dosages of the segregating parents

| Mating group | Polydactyly genotype and gene (*Po*) dose | Single polyphalangylism (SP) genotype and gene *($Po^{SP}$)* dose | Twin polyphalangyly (TP) genotype and gene *($Po^{TP}$)* dose | Number of ducklings produced |
|---|---|---|---|---|
| 1. | ♂: *PoPo* x ♀: *PoPo* 4 | 1<br>♂: Non SP (*popo*) x<br>♀: Unilateral SP ($Po^{SP}po$) | 2<br>♂: Bilateral TP ($Po^{TP}Po^{TP}$) x<br>♀: Non TP (*popo*) | 18 |
| 2. | ♂: *PoPo* x ♀: *popo* 2 | 0<br>♂: Non SP (*popo*) x<br>♀: Non SP (*popo*) | 2<br>♂: Bilateral TP ($Po^{TP}Po^{TP}$) x<br>♀: Non TP (*popo*) | 14 |
| 3. | ♂: *popo* x ♀: *PoPo* 2 | 2<br>♂: Non SP (*popo*) x<br>♀: Bilateral SP ($Po^{SP}Po^{SP}$) | 0<br>♂: Non TP (*popo*) x<br>♀: Non TP (*popo*) | 12 |
| 4. | ♂: *PoPo* x ♀:*PoPo* 4 | 2<br>♂: Bilateral SP ($Po^{SP}Po^{SP}$) x<br>♀: Non SP (*popo*) | 0<br>♂: Non TP (*popo*) x<br>♀: Non TP (*popo*) | 15 |
| 5. | ♂: *Popo* x ♀: *popo* 1 | 0<br>♂: Non SP (*popo*) x<br>♀: Non SP (*popo*) | 0<br>♂: Non TP (*popo*) x<br>♀: Non TP (*popo*) | 16 |
| 6. | ♂: *PoPo* x ♀: *PoPo* 4 | 1<br>♂: Non SP (*popo*) x<br>♀: Unilateral SP ($Po^{SP}po$) | 1<br>♂: Unilateral TP ($Po^{TP}po$) x<br>♀: Non TP (*popo*) | 15 |
| 7. | ♂: *PoPo* x ♀: *popo* 2 | 0<br>♂: Non SP (*popo*) x<br>♀: Non SP (*popo*) | 2<br>♂: Bilateral TP ($Po^{TP}Po^{TP}$) x<br>♀: Non TP (*popo*) | 14 |

Unilateral polydactyly has been reported as heterozygous condition of polydactylism (Landauer, 1948); hence genetically, the heterozygous polydactyly, single polyphalangism and twin polyphalangism was denoted as *Popo*, $Po^{SP}/po$and $Po^{TP}/po$, respectively while non-expression of the genes was represented as *popo*.

### *Incubation of eggs*

The experimental ducklings were produced by seven mating groups (MGs). The parent stock mated naturally and the eggs produced by each MG were incubated naturally by the female ducks for 35 days. The one hundred and four (104) ducklingsproduced by non-descript parents were then classified according to the expressed phenotypes as follows:

*Polydactylism***:** Ducklings with more than four toes on one or both feet were designated as having the polydactyly phenotype by visual inspection. In addition, all ducklings having five toes or more and those with polydactyly variant known as polyphalangylism (presence of extra phalanges on the first toe) (Landaeur, 1948; Robb and Delany, 2012) and on other toes were classified polydactylous.

*Polyphalangism:* A situation whereby the first inner toe (digit 1) is longer than usual first digit and could be expressed on one or both feet (Warren, 1944; Robb and Delany, 2012). This form of polydactyly termed polyphalangyly (Warren, 1944), results from the addition of an extra phalanx on the normal digit 1 rather than a duplication of the digit (Robb and Delany, 2012). The term was also applied to any other digit having elongated phalanx apart from the first digit in this study.

*Single polyphalangism (SP):* Expression of polyphalangism on digit one on a foot.

*Twin polyphalangism (TP):* Expression of polyphalangism on two digits (digit one and any other digit) on a foot.

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*Unilateral:* Expression of polydactylism and or its variants on one foot.

*Bilateral:* Expression of polydactylism and or its variants on two feet.

*Polydactyly types:* For the sake of brevity, the digits of ducklings were labelled from anterior to the posterior (Robb and Delany, 2012; Zhang *et al.,* 2016) for normal (non-polydactyl) and polydactyl ducklings. For non-polydactyl (normal) ducks with four digits on each foot, the digits were labeled 1 to 4 from the anterior to posterior position on the foot.

### *Statistical analyses*

Data were analysed using descriptive (percentage and bar chart) and inferential {Chi-square ($\chi^2$)} statistics. Chi-square procedure was used to test the observed number of polydactylous ducklings against the expected Mendelian values at 5% probability level. All statistical analyses were performed with SPSS (2001).

## Results

### *Incidence of polydactylysim in Muscovy ducks*

The incidence of polydactylism (Table 2) was prevalent in four mating groups (1, 3, 4 and 6) except in mating groups (MGs) 2 and 7 where 50.00% of ducklings were normal (non polydactylous) and MG 5 where non-polydactyl ducklings were prevalent (56.25%). In addition, polydactyl ducklings from all MGs were bilaterally polydactylous except two unilaterally polydactylous ducklings produced by MG 3 parents.

**Table 2.** Inheritance of polydactyl (*Po)* gene in Muscovy ducks

| Mating group | Parental genotype and gene dose | $Po^{TP}$ gene dose | Observed number (%)[1] | Expected number(%)[1] | Chi square($\chi^2$) |
|---|---|---|---|---|---|
| 1. | *PoPo* ♂ x *PoPo* ♀ 4 | 2 | 13[a] (72.22) | 18[a] (100) | 1.39NS |
| 2. | *PoPo* ♂ x *popo* ♀ 2 | 2 | 7[a] (50.00) | 14[a] (100) | 3.50NS |
| 3. | *popo* ♂ x *PoPo* ♀ 2 | 0 | 11[a] (91.67) | 12[a] (100) | 0.08NS |
| 4. | *PoPo* ♂ x *PoPo* ♀ 4 | 0 | 14[a] (93.33) | 15[a] (100) | 0.0.7NS |
| 5. | *Popo* ♂ x *popo* ♀ 1 | 0 | 7[a] (43.75) | 8[a] (50) | 0.25NS |
| **6.** | *PoPo*♂ x *PoPo* ♀ 4 | 1 | 12[a] (80.00) | 15[a] (100.00) | 0.60NS |
| **7.** | *PoPo* ♂ x *popo* ♀ 2 | 2 | 7[a] (50.00) | 14[a] (100) | 3.50NS |
| Tota | | | 71[b] | 96 | |

*[a]Values with similar superscripts along the row are not significantly (P>0.05) different*
*[1]Percentage of incidence in parenthesis*
*[b]All progenies were bilaterally polydactylous (69/71; 97.18%) except 2 (2/71; 2.82%) unilateral polydactyl ducklings in MG 3*
*NS: Not significant*

### *Types of polydactyly*

The relative distribution of polydactyly types (PTs) are presented in Table 3 and phenotypic expressions are represented in Figures 1 to 17. In addition, Figure 18 showed that the highest average number and highest number of PTs exclusively expressed by homozygous (MGs 1, 4 and 6) ducklings were higher compared to the heterozygous (MGs 2, 3, 5 and 7) ducklings.

**Figure 1.** Non polydactyly (Normal-digit)

**Figure 2.** Type 1 polydactyly (4-digit polydactyly)

**Figure 3.** Type 2 polydactyly (4-digit polydactyly)

**Figure 4.** Type 3 polydactyly (3-digit polydactyly)

**Figure 5.** Type 4 polydactyly (five-digit polydactyly

**Figure 6.** Type 5 poludactyly (5-toed polydactyly)

**Figure 7.** Type 6 polydactyly (5-toed polydactyly)

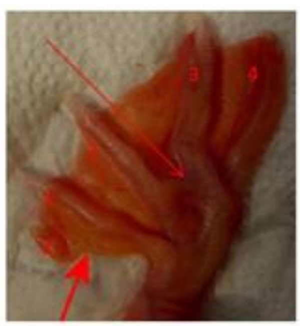

**Figure 8.** Type 7 polydactyly ((5-toed polydactyly)

**Figure 9.** Type 8 polydactyly (5-toed polydactyly)

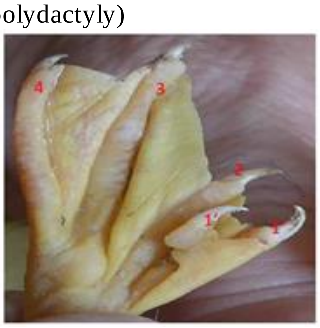

**Figure 10.** Type 9 polydactyly (5-toed polydactyly)

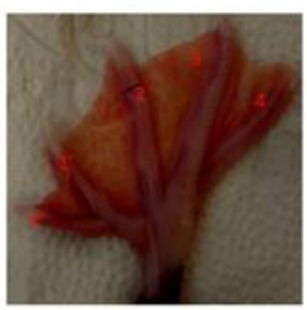

**Figure 11.** Type 10 polydactyly (5-toed polydactyly)

**Figure 12.** Type 11 polydactyly (5-toed polydactyly)

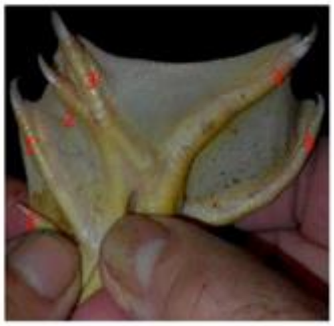

**Figure 13.** Type 13 polydactyly (6-toed polydactyly)

**Figure 14.** Type 14 polydactyly (6-toed polydactyly

**Figure 15.** Type 15 polydactyly (7-toed polydactyly)

**Figure 16.** Type 16 polydactyly (7-toed polydactyly

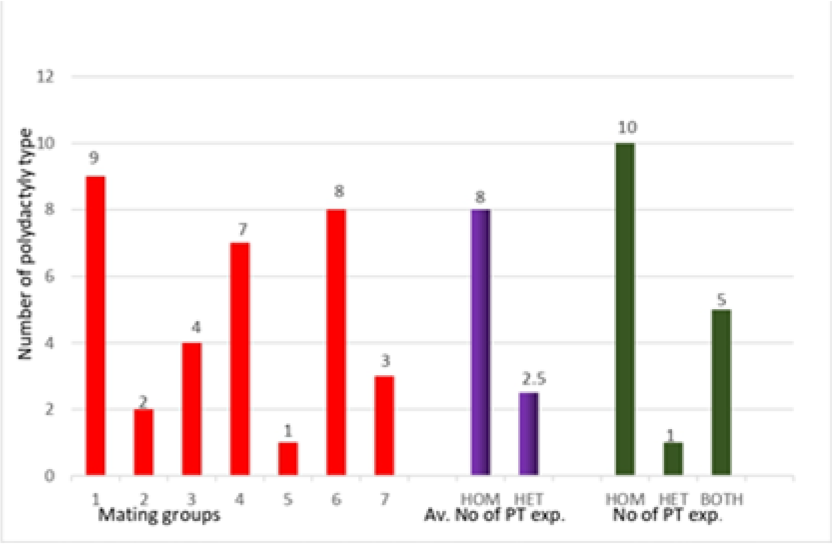


**Figure 18.** Relationship between number of polydactyly type, mating groups and ducking genotypes
*Av average;No Number;HOM Homozygotes;HET Heterozygotes;Exp Expressed;PT Polydacyty type*

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## Discussion

Empirical reports on incidence, inheritance, penetrance and expressivity of polydactyly in ducks are scanty (Napier, 1963; Oguntunji, 2018). Hence, there is paucity of literature for critical comparison with the present report. Nevertheless, results were compared with previous reports on chickens and other vertebrates.

*Incidence of polydactylism of Muscovy ducks*

Though *Po* gene had incomplete dominance/penetrance in ducklings produced by all MGs; however, the reported shortage of polydactyl ducklings was not significantly different from the expected proportions in all the MGs. In addition, the reported incomplete penetrance of the gene in the understudy population is congruent with the related reports on Muscovy duck (Oguntunji, 2018) and various breeds and lines of domestic chicken (Warren, 1941; 1944; Landauer, 1948; Zhang *et al*., 2016). Nevertheless, Robb and Delany (2012) reported full penetrance of the gene in the UCD-*Po* congenic line of chicken.

About the middle of the last century, Warren (1944) documented incomplete penetrance of *Po* gene in chickens and suggested that deficiency of hyperdactyls might be due to a number of conditions such as action of genetic suppressors or inhibitors to poor penetrance of the gene or to low viability of birds showing the character. In order to uncover the factor(s) responsible for the incomplete penetrance of *Po* gene in Muscovy ducks, comparison of the relationship between the incidence of *Po* gene and dosage effect of $Po^{TP}$ gene revealed/indicated that $Po^{TP}$ gene exerted influence on inheritance of polydactyly in the progenies of the MGs irrespective of the genotypes of the segregating parents.

For instance, non-twin polyphalangeal parents (MGs 3, 4 and 5) produced highest proportions of polydactyl progenies (MGs 3; 91.67%, 4; 93.33% and 5; 43.75%) and the proportions were very high and close to the expected frequencies (100.00% for MGs 3 and 4; and 50.00% for MG 5) compared with progenies of twin polyphalangous parents where the observed polydactyl ducklings were much lower (MGs 1, 72.22%; 2, 50.00%; 6, 80.00% and 7, 50.00%) than the expected proportion (100%).

The antagonistic effect of $Po^{TP}$ gene on incidence of polydactylism was evident further in progressive decrease in proportion of polydactyls as $Po^{TP}$ gene dosage increases. Highest incidence of polydactyly was observed in the progenies of non-twin polyphalangous parents {MGs 3 (91.67%), 4 (93.33%) and 5 (43.75% out of 50.00%)} compared with 80.00% and 72.22% proportion reported for progenies of 1 and 2-dose $Po^{TP}$ gene parents in MG 6 and 1, respectively. However, proportion of heterozygous polydactyl ducklings produced by 2-dose $Po^{TP}$ gene polydactyl parents (MGs 2 and 7) was much lower (50.00%) compared to those of homozygous (MGs 1, 4 and 6) counterparts. This trend suggests that the antagonistic/inhibiting effect of $Po^{TP}$ gene dosage on expression of *Po* gene was more pronounced in heterozygous ducklings than in homozygous ducklings. The previous report of Landaeur (1948) whereby selection for bilateral polyphalangism in chickens resulted in declined proportion of polydactyls lends credence to the result of the present study that polyphalangism is one of the genetic modifiers responsible for incomplete dominance cum penetrance of polydactyly in Muscovy ducks. Since absence of $Po^{TP}$ gene resulted in higher proportion of polydactyls in the present study and in chickens; this might probably explain the reason why Robb and Delany *et al*. (2012) reported complete penetrance of *Po* gene in non polyphalangous UCD *Po* genic line of chicken.

In view of the foregoing, it seems logical to conclude that one of the genetic modifiers/suppressors responsible for incomplete dominance/penetrance of *Po* gene in Muscovy duck is $Po^{TP}$ gene. Alternatively, it can be concluded that higher dosage of $Po^{TP}$ gene is antagonistic to the expression of *Po* gene; the higher the dosage of $Po^{TP}$ gene, the lower the proportion of polydactyls and vice versa. This submission agrees with the report of Corti *et al*. (2010) that polydactyly is a complex trait that is influenced by modifiers and suppressor genes. Furthermore, in spite of the absence of polyphalangeal genes ($Po^{SP}$ and $Po^{TP}$) in MG 5 parents, the penetrance of *Po* gene among progenies was very high

(43.75% of the expected 50.00%) but incomplete. This result indicated that polyphalangeal genes are not the only genetic factors responsible for incomplete penetrance of *Po* gene; but other yet-to-be-identified factor(s) contributed to its incomplete penetrance in Muscovy ducks.

Furthermore, the prevalence of bilateral polydactyly in the progenies of all MGs irrespective of the genotypes of the parents was in accord with similar reports on chickens (Landauer, 1948). This investigator worked extensively on the inheritance of unilateral and bilateral expressions of *Po* gene in chickens and reported a range of 82.50 to 100.00% in different mating groups. The prevalence of bilateral polydactylism among ducklings is indicative that this variant is the wild expression of the mutant trait in Muscovy ducks. In addition, though some unexpected non-polydactylous ducklings were observed among homozygous progenies (MGs 1, 4 and 6) in the present study, the presence of few normal offspring from homozygous parents is not uncommon. Warren (1944) and Landaeur (1948) had reported that where the two parents were homozygotes (*PoPo*), insignificant number of progeny were non-polydactylous (*po/po*) and heterodactylous.

Though the parent stocks in this study were sourced from unselected random bred population; however, the trend of inheritance of *Po* gene in all the MGs clearly demonstrated that polydactylism was inherited as an incomplete autosomal dominant trait in Muscovy ducks. This assertion is consistent with the consensus reports among researchers that *Po* gene is inherited as autosomal dominant in human and non-human vertebrates (Warren, 1941; 1944; Landauer, 1948; Zhang *et al*., 2016; Langel and Muller, 2017).

*Types of polydactyly*

***Type 1 Polydactyly***

The phenotype was expressed in 10 (11.36%) hyperdactylous ducklings. Members of the class have four metatarsals and four phalanges and its incidence was limited to four MGs (1, 3, 4 and 6). The striking difference of this variant with non-polydactylous (normal) counterpart (Figure 1) was the lengthening/elongation of digit 1. The digit 1 was observed to be as long as other digits. The digital conformation of this variant was represented as 4-3-2-2' and the polydactylous digit was labeled 2'.

Furthermore, the trend of incidence of Type 1 polydactyly is suggestive that sex of the parents was central to its expression. It could be deduced from Tables 1 and 6 that its expression was limited to the progenies of polydactylous dams (MGs 1, 3, 4 and 6) but not expressed in progenies of non polydactylous dams (MGs 2, 5 and 7).

***Type 2 Polydactyly***

One (1.14%) duckling in MG 3 expressed polydactyly type (PT) 2.Similar to PT 1, the variant had 4 metatarsals, 4 phalanges and elongated digit 1. However, the major anatomical architectural difference with PT 1 was the interdigital fusion of digits 2 and 3 around the middle region of the digits giving an 'H-shaped' inter-digital connection. The digital conformation was 4-3-2-2' and the polydactyl digit was labelled 2'.

***Type 3 Polydactyly***

The variant has 4 metatarsals and 5 phalanges and was expressed in two (2.27%) polydactyl ducklings.The striking anatomical feature was the short extra digit branching proximally from the metatarsal of digit 1. The digital conformation was represented as 4-3-2-1-1'. The polydactylous toe was labelled 1'.

***Type 4 Polydactyly***

This is the second most prevalent (28.41%) PT and also the prevalent PT among ducklings of MGs 3, 5 and 6. It is noteworthy that Type 4 polydactyly was expressed in all the MGs except MGs 2. Members of the class had 5 metatarsals and 5 phalanges and the auxiliary digit was the shortest. The digital conformation was 4-3-2-1-2' and the hyperdactylous digit was labelled 2'.

It is worth noting that all ducklings of non polyphalangous parents (MG 5) fully expressed it (100%). This probably suggests that polyphalangyl genes ($Po^{SP}$and $Po^{TP}$) are contributing genetic factors inhibiting full expression of Type 4 polydactyly in Muscovy ducks.

### *Type 5 Polydactyly*

This variant was the prevalent PT (31.82%) and was also the predominant PT among MGs 1, 2 and 7 ducklings. Members of this group have five metatarsals and 5 phalanges. The digital presentation was similar to the normal polydactyly (Type 4 polydactyly) but with a slight modification in lengthened/elongated digit 1 in contrast to the shorter digit 1 in PT 4. Digital conformation was represented as 4-3-2-1'-2' and the two polydactylous digits were labelled 1' and 2'.

### *Type 6 Polydactyly*

The variant was expressed in 3 (3.41%) ducklings and was characterized with five metatarsals and five phalanges. Similar to PT 5, polydactylism was expressed in the elongation of digit one and presence of extra anteriorly-placed digit. Nevertheless, the digital architecture was slightly modified with the presence of an elongated supernumerary toe. The digital conformation was represented as 4-3-2-1'-2' and polydactylous toes were labelled 1' and 2'.

### *Type 7 Polydactyly*

This type was expressed in one (1.14%) polydactyl duckling produced by MG1 parents. The variant has 6 digits comprising of 5 distinct metatarsals while the fifth (extra) digit is designated here as a false digit because it has only soft tissue connection to other structures of the feet. There is no phalangeal connection to the distally-developed metatarsal. Besides, there was a thin interdigital bone connecting digits 2 and 3 medially. Polydactylism was expressed in elongation of digit 1 and in presence and elongation of extra digit. Polydactylous digits were represented as 4-3-2-1'-2'.

### *Type 8 Polydactyly*

The variant was expressed in one (1.14%) duckling produced by MG 1 parents and its anatomical architecture was similar to PT 5. However, the major difference was the presence of interdigital bone connecting digit 1 and the supernumerary digit. The digital architecture was represented as 4-3-2-1'-2' and hyperdactylous digits were labelled 1'and 2'.

### *Type 9 Polydactyly*

This type has 4 metatarsals and 5 phalanges and was expressed in two (2.27%) ducklings produced by MGs 1 and 6 parents. The phenotype was characterised with the lengthening of digit 1 as well as it split into a parent and a daughter digit. It is noteworthy that the daughter digit was located ventral to its parent digit. The digital conformation was represented as 4-3-2-1'-1'. The hyperdactylous digits were represented as 1' and 1'.

### *Type 10 Polydactyly*

Two (2.27%) polydactyl ducklings, one each from MGs 1 and 6 expressed the variant. The class has four metatarsals and five phalanges. The anterior/first metatarsal was polydactylous and proximally bifurcated into two phalanges. The bifurcation was at the proximal junction of the medial one-third and contained bone and soft tissue. The digital conformation was represented as 4-3-2-1'-1' and polydactylous digits were represented as 1' and 1'.

### *Type 11 Polydactyly*

This PT has 4 metatarsals and 5 phalanges and was expressed in one (1.14%) duckling produced by MG 4 parents. Polydactylism was expressed in the elongation and duplication of digit two and lengthened digit one. Another conspicuous feature of the variant was the basal interdigital connection of metatarsals 2 and 3.This interconnection was located in their proximal one-third and contained soft tissue and bone. The digital conformation was represented as 4-3-2'-2'-1' and polydactylous digits were represented as 2', 2' and 1'.

### *Type 12 Polydactyly*

Two (2.27%) ducklings expressed the phenotype. This PT had 5 metatarsals and 6 phalanges. It is noteworthy that both hallux and auxiliary digits were lengthened. In addition, digit one was distally split to two with both containing soft tissue with bone and digital conformation was 4-3-2-1'-1'-2'. Digits expressing the mutant trait were represented as1', 1' and 2'.

### *Type 13 Polydactyly*

This class was expressed in one (1.14%) hyperdactylous ducklings of MG 4 and the variant has 5 metatarsals and 6 phalanges. Digit 2 was medially fused with the duplicated phalange of digit 3. Other conspicuous features were the proximal bifurcation of digit 3, elongation of digit 1 and presence of an extra digit. The digital conformation was represented as 4-3'-3'-2-1'-2' and polydactylous toes were labelled 1', 2', 3' and 3'.

### *Type 14 Polydactyly*

This variant was expressed by 7 (7.95%) polydactylous ducklings and was the prevalent PT among progenies of MG 4 parents. In addition, its expression was limited to MG 4 progenies and the variant was characterized with 6 toes. Furthermore, it is noteworthy that two auxiliary digits were present in the variant and the normal digit one was sandwiched between them. In addition, the anterior supernumerary digit was well formed and had distinct metatarsal while the posterior one had no metartasal but made up of tissue. The anatomical representation of the variant was 4-3-2-1'-1-1' and the two extra digits were labeled 1' and 1'.

### *Type 15 Polydactyly*

This variant was expressed by one (1.14%) duckling in MG 4. The variant had 7 toes comprising of 5 distinct metatarsals, 6 well developed phalanges and one digit made up of soft tissue. PT 15 is phenotypically similar to PT 14; however, the conspicuous distinguishing feature of PT 15 was the proximal duplication of digit 4. In addition, the anterior supernumerary digit was well formed and had distinct metatarsal while the posterior one had no metartasal but made up of tissue. The digital configuration was represented as 4'-4'-3-2-1'-1-1' and hyperdactylous digits were represented as 4', 4', 1' and 1'.

### *Type 16 Polydactyly*

The variant was expressed in one (1.14%) polydactyl duckling produced by MG 6 parents. The phenotype was characterized with 5 metatarsals and 7 phalanges. Polydactylism was expressed on metatarsals of digits 1 and 3 and presence of extra digit. In addition, digit 1 and 3 was distally and proximally bifurcated, respectively. Another conspicuous feature of the variant was the elongation/lengthening of extra digit, digits 1 and 3. The digital conformation was 4-3'-3'-2-1'-1'-2' and polydactylous digits were labelled as 3', 3', 1', 1' and 2'.

The absence of metatarsal in one of the extra digits of PTs 7, 14 and 15 was in accord with the submission of Lange and Muller (2017) that extra digits may represent isolated occurrences or belongs to various kinds of pathological syndromes, and the separation of the extra digits from the regular ones can be complete or incomplete, giving rise to different extents of fusion of supernumerary digits with other digits (synpolydactyly), either of the soft tissue alone or combined with skeletal fusions.

In addition, it could be inferred from the reported PTs that *Po* gene did not only influenced expression of extra (fifth) digit in Muscovy ducks, but its pleiotropic action also reflected in its expression on all digits concomitant with diverse digital anatomical architecture ranging from simple to complex digital conformation. This submission is in tandem with the report of Bond (1926) on domestic chicken that the the genetic factor influencing development of extra or fifth digit in the 5-toed breed is not limited to that special digit, but influences or may influence all the digits including the hallus on the inner or median aspect of the foot.

The underlying factors influencing the number of reported PTs among ducklings were multifaceted. Generally, dosage effect of *Po* gene wields influence on the number of PTs in different MGs. It could be inferred from Figure 18 that highest average number (8) of PTs was observed among homozygous progenies with 2 doses of *Po* gene {MGs 1 (9), 4 (7) and 6 (8)} compared to the much lower average number (2.5) in heterozygous ducklings of MGs 2(2), 3 (4), 5 (1) and 7 (3) with one dose of *Po* gene.

*Po* gene dosage effect was evident further whereby 10 (PT 7 - 16) of the 16 PTs were exclusively expressed in homozygous polydactyl (MGs 1, 4 and 6) ducklings while one (PT 2) was expressed by heterozygoutes and remaining 5 (PTs 1, 3, 4, 5 and 6) were expressed by both homozygotes and heterozygotes.

Furthermore, it seems the sex of the parents of heterozygous ducklings also influenced the number of PTs. It could be inferred from Tables 3 and Figure 18 that MG 3 ducklings having polydactylous dam had highest number of PTs compared to those with polydactylous sires (MGs 2, 5 and 7). In addition, the *Po* gene dosage of the parents appears to influence the number of PTs expressed among heterozygotes. Heterozygous ducklings having 2-dose *Po* gene parents (MGs 2, 3 and 7) had higher number of PTs (Figure 18) than those with one-dose *Po* gene parents (MG 5). Nevertheless, the asserted multifaceted factors are subjected to confirmation in controlled experiments with large data.

## Conclusion

It is evident that polydactyly was inherited as autosomal dominant trait but with incomplete penetrance in Muscovy ducks. It is well established that dosage effect of $Po^{TP}$genewas antagonistic to the expression of polydactyly and acted as genetic modifier/suppressor responsible for its incomplete dominance in Muscovy ducks. The dosage effect of *Po* gene influenced number of polydactyly types and highest number of polydactyly types was reported for homozygous polydactyl progenies compared to their heterozygous counterparts. Further empirical studies with more data would assist in validating the reported inheritance of polydactyly and observed polydactyly types in Muscovy ducks.

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