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Poultry breeding under public sector in India – Achievements and future perspectives: A comprehensive review

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ABSTRACT

Poultry sector in India is reaching new heights due to advances made in breeding, nutrition, health and management. Notably, poultry breeding has played a crucial role in the unprecedented growth and development of the sector through the selection of highly specialized sire and dam lines and subsequently, crossing them to produce varieties suited for commercial and backyard production. Government interventions and public sector institutions have been relentlessly working to make poultry farming remunerative in rural backyards. In this context, climate change, disease outbreaks, stagnant gains, welfare and ethical issues are the major challenges which call for immediate attention. Some possible interventions to address these issues include: incorporation of climate resilience and welfare traits in the selection indices for selection of birds, embarking on genome-based selection to exploit the genomic variability in the population for substantial gains, gene silencing and CRISPR/Cas9 mediated genome editing approaches for improving productivity and boosting immune responses. Collection and analysis of real-time data using artificial intelligence and data analytics will also help in improving predictions for health and welfare traits in poultry. This review provides a detailed account of the achievements of public sector with regard to poultry breeding in the country and presents future perspectives for continued viability and sustainability of the sector.

Keywords: Achievements, Future roadmap, Poultry breeding, Public sector, Research

Indian poultry sector has witnessed a remarkable growth over the years with 8-10% growth rate in broilers and 6-8% in layers (Chatterjee and Rajkumar 2015). Today, Indian poultry market is a USD 28.18 billion venture, growing considerably in the backdrop of demand driven by increased health consciousness, mushrooming of online food delivery platforms and rise in disposable incomes. At a Compounded Annual Growth Rate (CAGR) of 8.1%, it is expected to attain a worth of around 45 billion US dollars by 2028 (https://www.expertmarketresearch.com/reports/india-poultry-market). This could be attributed to a rapid jump in domestic egg and chicken production in commensuration with product diversification and value-addition (Nanda Kumar *et al.* 2022). Poultry keeping in India was largely a backyard venture before 1950s. High producing exotic breeds of poultry were imported from Israel, England and United States of America into the country during 1960s. There have been significant developments in the poultry sector over the last four decades with each decade focussing on different aspects. During the seventies, a spurt in egg production was witnessed, in the eighties, acceleration in broiler production was noticed and, in the nineties, advances in integration, automation and feed production had happened. The present decade promises to exploit value-added products and global trade avenues (Sridharan 2017).

According to BAHS (2022), the annual egg and meat production from poultry has increased by 47% and 25% over the past five years in the country. Along with the private sector, public sector (research) institutions have also greatly contributed to the phenomenal growth of the poultry production in the country. The progress made in the development of superior high-producing germplasm is a reflection of highly intense genetic selection followed by breeding for desired traits (Pym 2013). Pure-bred differentially selected sire and dam lines are being crossed in a systematic manner to develop birds with higher growth potential in broilers (Rajkumar *et al*. 2011a, Singh *et al*. 2012, Rajkumar *et al*. 2016) and higher egg production potential in layers (Reddy *et al*. 2001, Haunshi *et al*. 2009, Rajkumar *et al*. 2020a). However, most of the improvement in poultry production performance in the country has been achieved through quantitative genetic selection, i.e. by means of phenotype-based selection only (Pym 2013). Breeds/improved lines of *White leghorn, Cornish, Kadaknath, Aseel* and crossbred varieties like *Vanaraja*, *Gramapriya*, *Srinidhi, Janapriya, Krishibro, etc*. have been contributing significantly for improving

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the productivity of poultry farming and socio-economic upliftment of farmers (Singh *et al*. 2004, Haunshi *et al*. 2009, Debata *et al*. 2012, Kundu *et al*. 2015, Sarma *et al*. 2018, Haunshi and Prince 2021, Dalal *et al*. 2022).

The advent of genome-based or marker-assisted selection (MAS) has initiated further opportunities for genetic improvement in poultry on account of improved accuracy (Meuwissen *et al.* 2016, Wolc *et al*. 2016). This review is an exhaustive search of the available literature regarding poultry breeding research carried out by public funded institutions and organizations in India.

Poultry selection and breeding methodologies

Poultry breeding in India has historical underpinning in the practice of raising birds in the backyard for domestic consumption and game purposes (Rajkumar *et al*. 2021a). Before independence, poultry breeding was centred on selection of superior birds in a flock and selling of surplus culled birds as a terminal produce (Saxena and Kolluri 2018). Long term pure-bred selection using this approach led to a severe reduction in additive genetic variance over generations (Falconer and Mackay 1989). Thus, in 1980s, the concept of two-, three- and four-way crosses was adapted from crop breeding programmes to exploit the non-additive genetic variance component in poultry genome (Saxena and Kolluri 2018). Soon, efforts were made to develop commercial hybrids with high production potential as terminal produce with specialized sire and dam lines. Subsequently, focus was directed at developing specialized sire and dam parent lines with different selection parameters. *Cornish* males and *New Hampshire* females were highly preferred for production of broiler chickens whereas *White Leghorn* was the leading layer breed for white-shelled eggs and *Rhode Island Red* (RIR) for brown-shelled eggs (Bell 2002). Attempts to bring scientific modern poultry farming to Indian backyards got fructified with the development of *Giriraja*, a first synthetic chicken variety developed by the University of Agricultural Sciences, Bengaluru (Rajkumar *et al.* 2021a). Subsequently, several chicken crossbred varieties were developed for their suitability in rural, tribal and remote backyards of India by ICAR-Directorate of Poultry Research (DPR), Hyderabad; ICAR-Central Avian Research Institute (CARI), Izatnagar; State Veterinary and Agricultural Universities, etc.

At present, poultry breeding in India is a combination of pure-line selection (PLS) and crossing, to develop synthetic crosses suitable for further propagation (O'sullivan *et al*. 2010), and conservation and improvement of indigenous chicken breeds.

Pure-line selection: Specialized parent lines with desirable traits are developed through intense selection based on the desired objectives and goal. For production of commercial broiler stock, sire lines with higher body weight, robust body conformation, feed conversion, fertility, liveability and carcass quality are generally selected (Rajkumar *et al.* 2011a, Padhi and Chatterjee 2013, Padhi *et al.* 2015a, Rajkumar *et al*. 2021c) whereas egg production, egg mass, persistency, egg weight, egg quality, fertility, hatchability and age at sexual maturity are the criteria of selection in females (Rajaravindra *et al.* 2015, Prince *et al.* 2020, Rajkumar *et al*. 2021e). In layers, the prime focus is on increasing egg production without compromising egg weight and maintaining optimum egg quality. Layer breeders select females based on Osborne index for higher egg production and egg quality parameters (Debnath and Ghosh 2015, Chandan *et al.* 2019, Manjeet *et al.* 2019, Rajkumar *et al.* 2020a) while body weight and liveability are the major traits in case of layer males (Rajkumar *et al.* 2021d) in addition to the egg production. Simultaneously, a control population is also maintained to evaluate the rate of genetic progress in the selected population (Saxena and Kolluri 2018). Several short-term and long-term selection experiments have been done to evaluate the male and female lines for primary traits and correlated responses to other economic traits for improved productivity (Rajkumar *et al.* 2021b). A detailed list of traits considered as selection criteria in broiler and layer parent line is presented in Table 1.

Furthermore, in the view of impending climate change, heat stress is a major challenge for poultry breeders across the country. Fortunately, in poultry, major genes like naked neck (Na), frizzle (F), slow feathering (K), dwarf (dw), etc. could offer potential solutions for selection of climate-resilient birds in heat stress conditions (Fathi *et al*. 2022). Naked neck (Na) is an incompletely dominant gene which results in absence of feathers on the neck region. This allows for better heat dissipation and regulation of body temperature while maintaining normal production performance (Sharifi *et al*. 2010, Rajkumar *et al*. 2009, 2010, 2011a, b; Fernandes *et al*. 2023). Dwarf birds with sex-linked dwarf (dw) gene have better adaptability, reproductive fitness, feed efficiency and disease resistance than their normal-sized counterparts in hotter climates (Islam 2005). Also, the sex-linked slow feathering gene and incompletely dominant frizzle gene result in reduced feather mass and body weight, helping in better thermoregulation and encouraging higher meat and egg production in the tropics (Missohou *et al*. 2003, Fathi *et al*. 2013). Research on genetic basis of heat tolerance in poultry has been started long ago and the effect of these major genes on immunocompetence (Haunshi *et al*. 2002, Kundu *et al*. 2010), serum biochemical parameters (Rajkumar *et al*. 2010), egg production (Khan *et al*. 2007), egg quality (Rajkumar *et al*. 2009), growth and carcass traits (Rajkumar *et al*. 2011b) have been explored.

Development of crosses: Intense selection of pure lines is followed by crossing for exploiting the non-additive genetic component through heterosis. Considering the complementarity and nicking ability of sire and dam lines in view, these are crossed in different combinations to result in a hybrid heterozygous population with the desirable characteristics. These crosses may be of egg type, dual type and meat type depending on their utility with higher productivity compared to the native chicken. These hybrids

Table 1. Traits considered for selection of chicken broilers and layers

Type of chicken	Line	Selected for	Reference
Broiler males	Synthetic coloured broiler male line, PB-1	5 weeks body weight 6 weeks body weight	Reddy *et al*. (2018) Reddy *et al*. (2013)
	CSML	5 weeks body weight	Annual Report (2021-22)
	Vanaraja male line, PD-1	Shank length at 6 weeks	Rajkumar *et al*. (2016)
Broiler females	Synthetic coloured broiler female line, PB-2	Body weight at 5 and 6 weeks, 40 weeks egg production	Prince *et al*. (2020)
	CSFL	Body weight at 5 and 6 weeks, 40 weeks egg production	Annual Report (2021-22)
	Vanaraja female line, PD-2	Egg production at 40 weeks Egg mass at 52 weeks	Rajkumar *et al*. (2021e)
Layer males	*Gramapriya* male line, PD-6	Shank length up to 6 weeks of age	Rajkumar *et al*. (2021d)
	White Leghorn strains, IWH and IWI	Egg production up to 64 weeks	Kataria *et al*. (2015)
Layer females	White Leghorn line, IWK	Egg weight at 28 weeks and egg production up to 64 weeks of age	Haunshi *et al*. (2015b)
	White Leghorn Lines, IWH and IWI	Part period egg production up to 40 weeks of age	Bais *et al*. (2006)
	White Leghorn Lines, IWH and IWI	Osborne index for egg production up to 64 weeks	Haunshi *et al*. (2015b)
	Gramapriya female line, PD-3	Egg mass at 40 weeks	Rajkumar *et al*. (2020a)

are referred as the improved rural chicken varieties with faster growth rate of 1.5-2.0 kg (males) at 3 months of age and 120-180 eggs, almost 1.5 to 2 times of native chicken production. The resulting crosses are evaluated based on several parameters and the most suitable two-way or three-way crosses are further multiplied and propagated to the field for the benefit of the farmers in terms of higher yields and better returns (Rajkumar *et al*. 2021a). In recent times, several studies have been conducted to evaluate crosses suitable for rural and backyard poultry farming which have been detailed in Table 2.

Commercial poultry breeding in India

In India, poultry breeding is practiced parallelly using: highly improved layer and broiler genotypes for commercial production, and low-input dual purpose varieties and improved indigenous germplasm for backyard poultry production. Though initially, parent stock was imported from large breeding conglomerates to develop commercial broiler and layer varieties (Pym 2013), subsequently, several lines, varieties using two-way and three-way crosses were evolved for the genetic improvement programmes (Khan 2008, Padhi *et al*. 2015a, Rajkumar *et al*. 2018a, Rajkumar *et al.* 2021a).

The impact of commercial breeding on poultry industry could be adjudged by the fact that egg production from commercial poultry is an enormous 84.82% of the total egg production in the country. Also, the contribution of poultry meat (51.00%) to the total meat production of the country is almost completely met by the commercial sector only (BAHS 2022).

Contribution of Indian Council of Agricultural Research

All India Coordinated Research Project (AICRP) on poultry breeding started by the ICAR in 1970 during the IV five-year plan for improving the poultry production and productivity serves as a landmark development in the history of the country. Two projects namely AICRP on poultry for egg and meat were initiated under the umbrella of ICAR at ICAR institutes and State Agricultural Universities (https://aicrp.icar.gov.in/poultry/). In addition to the existing indigenous strains, four exotic *White Leghorn* strains for layer and four broiler strains were imported. After initial performance evaluation and their performance in cross combinations, six layer strains (IWH, IWI, IWD, IWF, IWN and IWP) and four broiler strains (PB-1, PB-2, CSML and CSFL) were selected for further genetic improvement and cross production (https://aicrp.icar.gov.in/poultry/achievements/salient-achievements/). Initially, a nucleus stock production unit was established at ICAR-Directorate of Poultry Research (DPR), Hyderabad for maintenance, multiplication and supply of parent lines and their commercial crosses developed by different AICRP centres. The institute was also entrusted with the additional responsibility to evaluate commercial layer and broiler varieties developed at different AICRP centres and to compare their performance vis-à-vis the varieties available in commercial hatcheries and private farms (Annual Report 2021-22). Combined efforts of ICAR-DPR and AICRP on poultry breeding led to the development of several promising high-yielding varieties of broiler and layer chickens suitable for commercial poultry farming in the country. *Athulya*, a layer variety capable of producing more than 300 eggs has been developed and propagated throughout the country. Layer varieties like *Krishi layer*, *ILI-80*, *ILM-90* and *ILR 90* and broiler varieties like *IBL-80*, *IBI-91*, *IBB-83* and *B-77* are a result of success of these endeavours only (Rajkumar *et al*. 2018b). Some of the highly popular and promising layer varieties have been

Table 2. Poultry crosses developed by public sector/research institutions in India and their performance under farm conditions

Purpose	Type of cross	Sire line	Dam line	Body weight. at 20 weeks in males (kg)	Annual egg production	Reference
Development of egg type backyard chicken variety	Three-way cross	PD-1 (Cornish) x IWI (White Leghorn) males	PD-3 (Dahlem Red) females	1.67 (at 16 wks)	233	Padhi *et al.* (2015b)
Development of a dual-purpose backyard variety (*Vanaraja*)	Two-way cross	PD-1 (Cornish) males	PD-2 (Dahlem Red) females	1.70	160	Padhi *et al.* (2012)
Development of egg type rural variety (*Gramapriya*)	Two way cross	PD-6 (Cornish) males	PD-3 (Dahlem Red) females	1.78	220	Rajkumar *et al.* (2018c)
Development of a dual purpose for free-range poultry farming	Two way cross	PD-1 (Cornish) males	PD-4 (Aseel) females	1.97	189	Rajkumar *et al.* (2019)
Development of egg type variety for rural poultry farming (*Janapriya*)	Three way cross	PD-1 (Cornish inheritance) x IWI (White Leghorn) males	PD-3 (Dahlem Red) females	1.62	228	Rajkumar *et al.* (2018a)
Development of meat type backyard variety (*Srinidhi*)	Two way cross	Control Broiler males	PD-3 (Dahlem Red) females	1.7-2.0	220-230	Rajkumar *et al.* (2021a)
Development of a broiler variety (*Krishibro*)	Two way cross	PB-1 males (Punjab Brown) males	PB-2 females (Punjab Brown) females	2.60	64 (at 40 weeks)	Haunshi *et al*. (2015b)
Development of a commercial layer variety (*Krishilayer*)	Two way cross	IWH (White Leghorn males)	IWI (White Leghorn) females		280	Haunshi *et al*. (2015b)
Development of crosses for rural poultry (*CARI-Shyama*)	Two way cross	Kadaknath males	CARI Red (Dahlem Red) females	1.12	210	Prakash *et al*. (2020)
Development of crosses for rural poultry (*CARI-Nirbheek*)	Two way cross	Aseel Peela males	CARI Red (Dahlem Red) females	1.84	198	Prakash *et al*. (2020)
Development of heat tolerant birds (*UPCARI*)	Two way cross	Native chicken with Frizzle plumage males	CARI Red (Dahlem Red) females	1.68	220	https://cari.icar.gov.in/varieties_deve.php
Development of heat tolerant birds (*HITCARI*)	Two way cross	Native chicken with naked neck plumage males	CARI Red (Dahlem Red) females	1.75	200	https://cari.icar.gov.in/varieties_deve.php
Development of chicken variety for backyard production (*Rajasri*)	Four way cross	Native males	RIR (Rhode Island Red) × WLH (White Leghorn) × DR (Dahlem Red) females	1-1.2	-	Rao *et al.* (2012)
Development of a dual-purpose bird (*CARI Debendra*)	Two way cross	Synthetic coloured broiler males	Rhode Island Red females	1.7-1.8 (at 12 weeks)	190-200	https://cari.icar.gov.in/varieties_deve.php

Composition of different lines are: PD-1: Cornish inheritance; PD-2 & PD-3: Dahlem Red inheritance; PD-4: Aseel inheritance; PD-6: Cornish inheritance; PB-1 & PB-2: Punjab Brown inheritance; IWH & IWI: White Leghorn inheritance; CARI Red: Dahlem Red inheritance.

Table 3. Commercial layer chicken varieties developed by ICAR-DPR and AICRP on Poultry Breeding (Rajkumar *et al*. 2018b)

Variety	Developed by	Egg production up to 72 weeks (Nos.)	Age at first egg (days)
Krishilayer	ICAR-DPR, Hyderabad	270-290	140-150
Athulya (ILM-90)	AICRP on Poultry Breeding, KVASU, Mannuthy, Kerala	303	-
Anand commercial layer	AICRP on Poultry Breeding, AAU, Anand, Gujarat	300	142
ILR-90 Jubilee	Veterinary college, Hyderabad	296	156

detailed in Table 3.

Government support to the poultry sector encouraged the private firms to enter into poultry breeding and production. Venkateswara Hatcheries Pvt. Ltd., Pune pioneered the poultry breeding operations on large scale with pureline breeding followed by many other firms like Suguna, Indian Broiler, Aviagen, Srinivas, etc.

Also, ICAR-Central Avian Research Institute (CARI), Izatnagar has significantly contributed to the commercial poultry farming by developing and releasing several high-yielding commercial layer and broiler stock. The institute is one of the leading centres of AICRP on poultry breeding and is developing commercial germplasm for wide spread dissemination. Some of the major contributions of the centre to the commercial poultry farming in the country have been enlisted in Table 4.

Backyard poultry breeding in India

Though backyard poultry contributes just 15.18% of the total egg production (BAHS 2022), its impact in terms of providing nutritious food, ensuring health and well-being and socio-economic upliftment in rural, tribal and remote corners of the country is hugely significant. This is due to the reason that around 65% of Indian population resides in villages where protein intake is very low (Rajkumar *et al*. 2021a). Realizing the potential of backyard poultry farming in providing nutritional security, fighting protein malnutrition, promoting economic equity and facilitating women empowerment in the rural areas of the country (Kumar *et al*. 2019), the Government of India has promoted several initiatives and schemes in this area. These include the re-orientation of AICRP on Poultry Breeding to focus especially on rural poultry (Annual Report 2021-22). Morphological features like coloured plumage, comb pattern combined with better adaptability and performance (survivability, body growth and optimum production on a low plane of nutrition) have been identified as breeding goals for development of rural chicken varieties (Ayyagari 2001, Dana *et al*. 2010, Neeteson *et al*. 2023). These goals are being achieved through selective breeding of indigenous or exotic breeds and crossbreeding of selected lines to develop rural chicken varieties (Haunshi and Sharma 2002, Haunshi *et al*. 2015a, Rajkumar *et al*. 2021c). Crossbred chicken varieties like *Gramapriya, Vanaraja, Srinidhi* have been developed using selective breeding of exotic germplasm and are being successfully propagated to rural and tribal backyards for sustainable production and incomes (Rajkumar *et al*. 2018b). Also, varieties developed using improved native chicken breeds are in huge demand owing to the superior genes related to meat and egg quality/flavour, broodiness, better adaptability and disease resistance in the latter (Kanakachari *et al*. 2022).

Role of ICAR-DPR in improvement of backyard chickens

ICAR-DPR, Hyderabad started its quest for development of rural chicken varieties way back in 1996-97. Today, rural chicken varieties developed by the directorate constitute around 8% of the total improved poultry chicken germplasm in the country (Rajkumar and Rama Rao 2018).

Vanaraja: This dual purpose chicken variety was developed by the directorate in 1999. It is a resilient variety with better immune competence and multi-coloured plumage. *Vanaraja* cocks weigh 1.5-1.7 kg at three months and hens lay 110-120 eggs under backyard conditions.

Table 4. Commercial stock developed by ICAR-CARI (https://cari.icar.gov.in/varieties_deve.php)

Commercial layer varieties			
Variety	Egg production up to 72 weeks (Nos.)	Age at first egg (days)	Average egg weight (g)
CARI Priya (ILI-80) (White egg variety)	>298	119-126	57
CARI Sonali (Brown egg variety)	>280	126-133	54
Commercial broiler varieties			
Variety	Body weight at day old (g)	Body weight at 6 weeks (g)	Feed conversion ratio up to 6 weeks
CARIBRO Vishal (White Broiler)	43	1650-1700	1.85
CARIBRO Dhanraja (Coloured Broiler)	46	1500-1700	1.92
CARIBRO Mrityunjay (for hot and dry regions with naked neck character)	38-42	1400-1500	1.95
CARIBRO Tropicana (for hot and dry regions with frizzle feathers)	-	1300	1.90

Vanaraja has made huge inroads across the length and breadth of the country and is highly popular among the rural populace (Mondal and Kakati 2010, Islam *et al*. 2014, Kundu *et al*. 2015, Perween *et al*. 2016, Kumar *et al*. 2021).

Gramapriya: It is another success story for egg-type backyard poultry farming. It is a prolific brown egg layer capable of producing 160-180 eggs in backyard and cocks weigh about 1.5 kg at three months of age. Owing to its great demand, this variety has been supplied to several Government agencies including KVKs, State Animal Husbandry departments, Central Poultry Development Organizations and Poultry Seed Project centres located throughout the country. This variety commands huge appeal throughout the country from Jammu and Kashmir (Singh *et al*. 2018) in the north to Tamil Nadu (Jagatheesan *et al*. 2020) in the south and from Maharashtra (Kumar *et al*. 2017) in the west to Manipur in the north-east (Hajra *et al*. 2014).

Srinidhi: *Srinidhi* is another dual-purpose variety which was developed in 2013 to obtain higher body weight of *Vanaraja* along with higher egg production of *Gramapriya* in a single bird. *Srinidhi* hens lay about 150 eggs in backyard conditions. The variety is multi-coloured and attains juvenile body weight of 600-650 g at 6 weeks of age. This backyard variety is also available pan-India and is performing well under diverse climatic conditions (Sarma *et al*. 2018, Khan *et al*. 2019, Pankaj *et al*. 2019).

Swetasri: *Swetasri* (PD-2 × White Leghorn line*)* is an egg type variety, popularly known as *White Gramapriya* which can lay about 180-200 eggs a year under field conditions. This variety is preferred in the remote areas of Kerala and Lakshadweep islands for semi-intensive and small-scale intensive farming systems (Rajkumar *et al*. 2018b).

Krishibro: This variety is the result of the vision to develop a meat type bird suited for small-scale intensive farming in rural and tribal areas. It has multi-coloured plumage and can attain 1.5 kg body weight at six weeks of age on a low plane of nutrition. Sometimes, 2 kg body weight even before 35 days of age has been reported in these birds (Rajkumar *et al*. 2018b).

Genetic improvement using native chicken germplasm

Native chickens are endowed with superior traits like broodiness, heat tolerance, disease resistance, resilience, fighting against predators, good flight, ability to survive and produce on scavenging or low input diet (Kanakachari *et al*. 2022). All these traits assume huge significance in the light of challenges like climate change, disease outbreaks, shrinking resources and welfare issues (Hafez and Attia 2020, Duncan 2001). Therefore, native birds are being improved for their production performance while retaining their original phenotypic and behavioural traits (Chatterjee *et al*. 2007, Haunshi *et al*. 2011, Haunshi *et al*. 2012). In this regard, *Aseel* (Haunshi *et al*. 2019), *Kadaknath* (Pal *et al*. 2019, Haunshi and Sharma 2002), *Ghagus* (Haunshi *et al*. 2022) and *Nicobari* (Niranjan *et al*. 2008, Haunshi *et al*. 2020) are being improved for growth, production, reproduction and immune response traits. This is being done through selective breeding for desirable traits in the indigenous breeds to develop specialized lines (morphological, growth, production and carcass quality) (Rajkumar *et al*. 2017, Haunshi *et al*. 2019, Dalal *et al*. 2022, Haunshi *et al*. 2022). *Vanashree* is one such improved native chicken line (PD-4) evolved from *Aseel* breed which is selected for higher body weight at 8 weeks and egg production up to 40 weeks of age (Haunshi *et al*. 2021). Subsequently, this native germplasm is crossed with improved exotic lines to get F1 generation with 50% native inheritance. F1 is further crossed again with improved exotic lines to get a desired terminal cross with 25% native and rest of the exotic inheritance (Annual Report 2021-22). *CARI Nirbheek* (Aseel cross), *CARI Shyama* (Kadaknath cross), *UPCARI* (Indian native chicken with frizzle plumage cross) and *HITCARI* (Indian native chicken with naked neck plumage cross) are the examples of the crosses of exotic breed (*Dahlem Red*) with native chicken germplasm developed by ICAR-CARI, Izatnagar (https://cari.icar.gov.in/varieties_deve.php).

On similar lines, AICRP on poultry breeding was overhauled in 2014-15, to develop location-specific chicken varieties and their dissemination in villages; for conservation, improvement, characterization and application of local native and elite layer and broiler germplasm; to develop package of practices for village poultry and entrepreneurships in rural, tribal and backyard areas, etc. (Annual Report 2021-22). In order to accomplish these objectives, separate breeding strategies have been devised to develop egg-type, meat-type and dual-purpose birds.

Several location-specific and region-specific varieties of rural poultry have been developed as a result of AICRP endeavours (Table 5). Different centres of the project identify local non-descript breed of chicken to develop a variety suited to the demands of rural population of the region. The developed location-specific varieties have been found to have better adaptability and performance in the specific regions owing to the favourable genotype-environment interactions combined with selective breeding and crossbreeding (Rajkumar *et al*. 2018b).

Future perspectives

Sustained efforts in poultry breeding and genetic improvement have ushered in the silver revolution and contributed immensely to the pink revolution in the country. However, Indian poultry breeding is still faced by numerous issues and challenges which need to be addressed immediately. Climate change, more evident in the form of heat stress is one serious challenge (Nyoni *et al*. 2021) which threatens to disturb the poultry production systems, especially in rural areas (Nyoni *et al*.2018). Elevated temperatures beyond thermoneutral zone will lead to reduced feed intake, slower growth rate, lower hen-day egg production, reduced immunity, thus causing a detrimental

Table 5. Location-specific dual purpose chicken varieties developed by different AICRP centres and their performance in backyard conditions (Rajkumar *et al*. 2018b)

Variety	Developed by AICRP centre	Suited for region/state	Genetic make-up	Body wt. at 20 weeks (kg)		Body wt. at 40 weeks (kg)		Annual egg production (Nos.)	Egg weight at 40 weeks (g)
				Male	Female	Male	Female		
Pratapdhan	MPUAT, Udaipur	Rajasthan	Native × PB-2 × RIR	2.4	1.9	2.7	2.2	165	53.8
Narmadanidhi	NDVSU, Jabalpur	Madhya Pradesh	Kadaknath × Jabalpur colour	1.6	1.4	2.3	1.7	170	48.0
Kamrupa	AAU, Guwahati	Assam	Native × PB-2 × DR	1.3-1.5		1.8-2.2	1.3-1.6	118-130	52.0
Jharsim	BAU, Ranchi	Jharkhand	PB-2 × Desi × DR	1.6-1.8		-	-	110-130	52-55
Himsamridhi	CSKHPKV, Palampur	Himachal Pradesh	(DR × Native) × DR	1.7	1.2	2.1	1.6	140	53.0

impact on the welfare and productivity of birds (Wasti *et al*. 2020, Abioja and Abiona 2021). Although breeding for thermotolerance in chickens through introgression of major genes [like Naked neck (Na), Frizzle (F), Dwarf (dw) and slow feathering (K)] (Wasti *et al*. 2020) has been going on since long, selection for traits related to heat tolerance (Mashaly *et al*. 2004) and favourable genotype-environment interactions (Chu *et al*. 2019) could be a potential solution in the direction of raising climate-resilient birds. In this context, genetic markers can be identified and utilized to enhance thermotolerance and productivity of birds in tropical conditions (Nawab *et al*.2018[Vandana *et al*. 2021).

Poultry diseases present an ever-existing threat to the breeding systems and can potentially wipe out the entire gene pool meticulously selected over generations (Akintunde and Adeoti 2014). Indiscriminate focus on increasing productivity levels has unintendingly led to disease susceptibility and antimicrobial resistance in poultry (Abreu *et al*. 2023). Therefore, there is growing concern regarding the welfare of birds and boosting their natural immunity and disease resistance (Hafiz and Attia 2020). From breeding perspective, a viable approach could be designing selection indices giving appropriate weightages to production, health, livability and reproduction (Kumar *et al*. 2023). Simultaneously, the indigenous poultry germplasm needs to be rapidly characterized and explored to identify disease tolerance genes before they are lost forever.

Poultry breeding is highly competitive and needs continual genetic progress to sustain itself (Preisinger 2018). Though phenotype-based selection is still yielding handsome returns, it is not long before poultry breeders/geneticists will have to embark on genomic selection of quantitative traits for extensively capturing the genomic variability and yielding sustainable gains. With declining costs of genotyping and improving computational abilities, there is an opportunity to increase the accuracy of EBV for sex limited traits (Meuwissen *et al*. 2016). However, genome-based breeding programmes in poultry should employ large scale genotyping along with stringent sample tracking to be successful. Nonetheless, high density (HD) SNP genotyping (600K chicken SNP chip) along with genomic prediction and selection is an exciting area in poultry breeding to improve production, disease resistance, climate resilience and carcass quality traits altogether. To start with, we can go for HD genotyping of few families and subsequently, develop computational abilities to select for higher densities using low density chips later by genotype imputation (Habier *et al*. 2009).

Recently, gene editing systems like (CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats)/Cas9 and gene silencing by RNA interference is being employed to increase the genetic variation in poultry flocks. This is aimed at improving the egg production, enhancing bird's immune response and producing leaner meat (Khwatenge and Nahashon 2021). Recent findings indicate that RNAi

mediated gene silencing of Myostatin receptor gene *ACVR2B* improves the body weight and carcass traits in juvenile chickens (Bhattacharya *et al*. 2019). In a similar approach, Activin type IIB receptor was silenced to generate a knockdown chicken with greater muscle mass (Vishnu *et al*. 2019). Genome editing is also being advocated as a potential solution to animal welfare issues like sex selection and culling through *in ovo* sexing (Lee *et al*.2019).

With the rise in consumer awareness and ethical concerns, poultry breeding decisions should accommodate the conflicting demands of welfare along with food security and climate change (Neeteson *et al*. 2020). Hence, poultry breeders need to identify the individual traits relevant to health and welfare of birds (Star *et al*. 2008). These can include low heritability traits like cannibalism, bone strength, leg score, pecking, robustness, mortality, disease resistance, etc. and other social effects. Selective breeding for these health and welfare related traits (along with management practices) can be a potent tool for poultry breeders to mitigate the ethical challenges posed by intensive poultry farming. Also, genomic selection should incorporate these traits to further bring sustainability in the poultry sector (Muir *et al*. 2014).

Advent of artificial intelligence (AI) and Internet of Things (IoT) presents a great opportunity for poultry breeders to analyse large volumes of precisely collected data for making predictions (Astill *et al*.2020). The data related to poultry health, production and management conditions captured using sensors, video and image processing capabilities and sound or vocalization based analysis (Singh *et al*. 2020) can greatly help the breeders to collect physiological health data for deducing genetic parameters related to bird stress, health and mortality (Aydin 2017a, Aydin 2017b, Wu *et al*. 2022, Park *et al*. 2022). Also, real-time data of images and sound analysis can provide interesting genetic insights on production and feed intake parameters (Aydin *et al*. 2015, Park *et al*. 2022).

Conclusion

Indian poultry sector has made headways globally due to the immense progress made in poultry breeding. Both commercial and backyard breeding systems have contributed to the phenomenal growth of the poultry sector in the country. Also, it has nutritional security, socio-economic equity, health and well-being of the population. However, climate change, diseases, falling gains and welfare issues are some of the challenges faced by Indian poultry sector today. These need to be appropriately addressed in the future poultry breeding strategies of the country. Developing selection indices with weightages to health and welfare traits along with production, genomic selection for climate resilience, gene editing for enhancing genetic variation, use of artificial intelligence and big data analytics for precise selection are proposed as measures for future development and sustainability of the poultry breeding sector in the country.

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