Tropical Animal Health and Production (2021) 53: 176
https://doi.org/10.1007/s11250-021-02621-6

REVIEWS

Backyard poultry farming for sustained production and enhanced nutritional and livelihood security with special reference to India: a review

U. Rajkumar[1] · S. V. Rama Rao[1] · M. V. L. N. Raju[1] · R. N. Chatterjee[1]

Received: 19 October 2020 / Accepted: 10 February 2021 / Published online: 20 February 2021

Abstract

A comprehensive review on backyard poultry farming (BYPF) was carried out with respect to history, status, production systems, management practices, role in socio-economic development, etc., considering the Indian scenario in particular. Backyard poultry is an age-old traditional practice where small numbers of native chickens are reared with or without inputs under the free-range scavenging conditions. Currently, BYPF contributes about 17.8% (18.41 billion) of the total egg production (103.32 billion) of India. The introduction of high yielding chicken varieties, which resemble the native chicken, transformed the BYPF into a highly remunerative farming activity. The BYPF has a proven potential to alleviate poverty, eradicate malnutrition, empower women, and provide subsidiary income, and gainful employment in rural and tribal areas. In India, four types of backyard poultry farming are practiced, i.e., traditional, small-scale rural, small-scale intensive, and native chicken farming. The aspects of breeding and nutritional strategies in the nursery, and free-range conditions, besides the housing and health care practices that are followed in India, are discussed in detail. Backyard poultry farming has huge potential for further expansion as the produce from this system is preferred across the country.

Keywords Breeding · Nutrition · Health · Indigenous chicken · Improved varieties · Free-range farming

Introduction

Globally, the majority of chicken meat and eggs come from the intensive production system, which is based on high input costs in terms of technology, capital, chicken varieties, management, etc. Though poultry development in India has taken a quantum leap in the last five decades, the growth has been mainly confined to the commercial poultry sector, which is centered in and around urban and peri-urban areas. Access of people in rural/tribal areas to eggs and chicken meat from intensive farming is limited due to the lack of cold chain facility and the negligible demand for processed and stored chicken meat. In India, about 65 percent of the human population lives in villages where the staple food is either rice or wheat and the protein intake is considerably low. It is essential to provide nutritious food with supplementation of animal protein to these rural and tribal people to protect them from protein malnutrition and ensure their proper growth, and sound health. Though the intensive production system is well established, backyard poultry farming (BYPF) with improved chicken varieties or native breeds is gaining popularity in the recent past as a potential tool to alleviate protein hunger and generate subsidiary income among the rural and tribal people across the country.

The present review brings out the status of backyard poultry farming in India, and its role in rural livelihoods along with the challenges and opportunities for various stakeholders, i.e., the traditional farmers, and the entrepreneurs, who wish to venture into the activity.

History

Backyard poultry is an age-old practice in India, especially in rural areas, wherein small numbers of native chickens are reared by households either for domestic consumption and

✉ U. Rajkumar
ullengala@yahoo.com

[1] ICAR-Directorate of Poultry Research, Rajendranagar, Hyderabad, Telangana 500 030, India

or for game purposes. The evidence of chicken domestication dates back to 2500 BC from the Indus valley civilization (Zeuner 1963) and further up to the ancient neolithic era of 6000 BC from China (West and Zhou 1988). Domestication was followed by migration of chickens from Asia to Europe, Africa, and America (Crawford 1990) leading to diversity in the chicken population, which can be categorized into traditional, standardized breeds, and selected lines. The Red jungle fowl (Fig. 1) is considered to be the progenitor of the domesticated chicken over the years. Poultry and humans have shared history for thousands of years and still continuing and will continue in the future also (Alders 2012). Small-scale family poultry production is an essential part of human societies and culture over the years in developed, developing, and underdeveloped countries.

The backyard poultry though existed for ages in villages; the modern scientific backyard poultry farming started about four decades ago in India with the initiation of research on the development of high performing bird suitable for rural/backyard/village/family poultry farming. The University of Agricultural Sciences, Bangalore was the front runner in this regard, where research efforts were initiated during the 1980s. *Giriraja* (Figs. 2 and 3) was the first synthetic chicken variety developed by this University, which was released during 1989 for farmers (Ramappa 2001). The development of the *Giriraja* bird has resulted in a paradigm shift in poultry breeding activity in the country towards the rural poultry. The ICAR - Directorate of Poultry Research, Hyderabad, a premier institution under the aegis of Indian Council of Agricultural Research, initiated the research work on the development of chicken varieties suitable for BYPF during 1992 and eventually developed a dual-purpose chicken variety, *Vanaraja* (Figs. 4 and 5) and released for farmers during 1999 (Ayyagari 2001). *Vanaraja* has revolutionized the BYPF concept in India as the birds were accepted by the farmers across the country in different agro-climatic regions (Sharma and Chatterjee 2009; Rajkumar et al. 2010). Subsequently, *Gramapriya* (Fig. 6), a brown egg layer variety was developed at ICAR-DPR, Hyderabad (Ayyagari 2001). The success of these varieties in the rural backyards has led to the development of many other improved varieties by

Fig. 1 Red junglefowl flock

Fig. 2 Giriraja cock

different agricultural/veterinary universities and ICAR institutions. The rural chicken varieties have special attributes both in terms of qualitative traits like multicolored plumage patterns, meat quality, majestic gait and appearance, and quantitative traits such as lean body weights, longer shanks, relatively higher immune competence, and hardiness (Sharma and Chatterjee 2009; Rajkumar et al. 2010). The important traits like shank length, egg production, and immune competence are being further improved over the years through selection in parent lines of these varieties (Rajkumar et al. 2016b; Rajkumar et al. 2020a). The Govt. of India has considered backyard poultry as one of the potential tools for alleviating protein malnutrition among rural and tribal people and promoted BYPF through various developmental schemes.

Status

Backyard poultry contributes about 17.8% (18.41 billion) of the total egg production (103.32 billion) of India (BAHS 2019). Of the total egg production from the BYPF, the native fowls produce about 11.9 billion eggs, the improved fowls lay about 5.19 billion eggs, while other avian species produce

Fig. 3 Giriraja hen

Fig. 4 Vanaraja cock

1.32 billion eggs in the country. India ranks 3rd in egg production and 5th in meat production in the world and the per capita availability is 79 eggs and 3.12 kg chicken meat per annum. The availability of eggs and chicken meat is highly variable in different parts of the country due to disparities in production levels and their transportation and availability between urban and rural areas (Chatterjee and Rajkumar 2015).

Characteristics of backyard poultry

Backyard poultry is a low input or no input activity primarily depending on scavenging on the natural feed base with little supplementary feeding, night shelter, and minimum health care practices (Sharma and Chatterjee 2009; Rajkumar et al. 2010; Sheikh et al. 2018; Islam et al. 2020). Backyard poultry is characterized by the rearing of chicken in small units (10–20 birds per household) primarily for family consumption and game purpose in social events. The birds scavenge for feed, consume household waste and insects, and also utilize the resources that are not directly useful to human beings or livestock. The native chickens grow slow and lay fewer eggs, but

Fig. 5 Vanaraja hen

Fig. 6 Flock of Gramapriya birds under free-range conditions

are widely accepted by the rural and tribal people across the country. Photographs of some important native chicken breeds of India are provided in Figs. 7, 8, 9, 10, and 11. However, for increasing the productivity of chickens under the BYPF, there is a need to develop birds with genetic potential for enhanced growth and egg production. The chicken varieties thus developed for BYPF should resemble the native birds with multicolored plumage, longer shanks, higher productivity, easy adaptability, and better immunity, besides being able to perform on a low plane of nutrition. Plumage color and comb type are the important traits, which determine consumer acceptability and market demand (Rajkumar et al.

Fig. 7 Aseel cock

Fig. 8 Aseel cock

2010; Rajkumar et al. 2017; Rajkumar et al. 2019; Dana et al. 2010).

The BYPF has a proven potential to alleviate poverty, eradicate malnutrition, generate subsidiary income, empower women, and provide gainful employment in rural and tribal areas of the country (Sharma and Chatterjee 2009; Rajkumar et al. 2010; Rajkumar and Rama Rao 2015; Chatterjee and Rajkumar 2015; Islam et al. 2020). The BYPF is considered as an integral part of many families and as an income generating activity in developing countries for women (FAO 2007; Sambo et al. 2015) with locally available low-cost inputs like household waste, green fodder, and insects, besides a small amount of supplementary feed. Women manage most of the activities of BYPF like feeding, watering, cleaning, and selling of chickens, and eggs and 95% of the village poultry flocks are owned and managed by women in Zimbabwe

Fig. 9 Aseel hens

Fig. 10 Kadaknath birds

(Mapiye et al. 2008) and in many regions of the world which leads to their empowerment (Sharma and Chatterjee 2009; Rajkumar et al. 2010; Alders et al. 2018).

The BYPF is comprised of two phases of rearing, i.e., nursery and free-range rearing for the sustenance of the activity.

Nursery rearing

Rearing of newborn chicks by artificially providing all the requirements (warmth, feed, protection from the predators, etc.) that are provided by the mother to young chicks is called nursery rearing. The management of backyard type chicks during this phase resembles that of intensive poultry farming in terms of feeding, management, and health care practices. Chicks are reared in this system till they grow enough to protect themselves from the predators and start scavenging for feed, which is usually practiced up to 4–6 weeks of age.

Free-range rearing

The chicks are introduced into the farmer's backyards at 4–6 weeks of age depending on the environmental temperature.

Fig. 11 Ghagus birds

The number of chicks per household depends on the area and the natural food base available. However, a unit with 15 to 20 birds per household is ideal for the successful and effective management of birds. Under the small-scale free-range system, up to 200 birds are reared in orchards with a large foraging area and a poultry house for night shelter. Supplementary feeding is essential in this system for realizing optimum productivity from the birds. The birds are let out for foraging during the daytime and kept in night shelters or houses during the night. Based on natural food availability, the birds have to be provided with supplementary feed (cereal grains and oilseed cakes) in the evening to meet the approximate requirements of essential nutrients. Generally, birds meet their protein requirements through scavenging on insects, worms, etc. available in backyards. Feeding the birds with available cereals is always beneficial to sustain the production. During the laying phase, calcium supplementation (shell grit, stone grit, or lime powder) is essential to avoid the production of shell-less eggs and broken eggs.

Production systems

The FAO classified family poultry production systems into small-scale extensive scavenging, scavenging, semi-intensive, and small-scale intensive (FAO 2014) systems. In India, the BYPF is practiced prominently in four different systems as discussed below. The selection of system is based on the demand in the local market (eggs or meat), availability of natural food base, food habits of the population, etc.

Traditional backyard system

Traditional backyard farming is an age-old practice prevalent in rural and tribal villages of the country with few numbers of birds (less than 20) with little or no inputs. The fertile eggs produced are hatched to provide replacements and the birds feed by scavenging or are provided with household leftover food, and crop by-products. The introduction of high yielding improved chicken varieties with scientific intervention in terms of supplementary feeding, and health care practices made the system sustainable with increased productivity from the BYPF. The number of birds may go up to 50 birds in this system, provided there are enough scavenging areas and supplementary feeding. This occupies more than 70% of the backyard poultry activity in India. In this system, surplus males are disposed of at about 3 months of age for meat purposes and the females are retained for egg production.

Semi-intensive farming

Semi-intensive system of BYPF has a flock size of 50–200 or more, where birds are reared under semi-scavenging conditions with supplementation of 30–40% of feed requirements. Supplementary feed is offered generally in the evening hours based on the availability of the natural food base in the specific region and season. Often, this type of system is practiced in orchards and gardens with a poultry house as night shelter or shade during sunny days and a free-range area for scavenging during day time. About 10–15% of backyard poultry is reared in semi-intensive type. In this system also, surplus males are sold at about 3 months of age and the females are retained for egg production.

Small-scale intensive farming

Small-scale intensive farming comprises more than 200 to a few thousands of birds, which are reared by providing all the inputs similar to the intensive broiler farming till they attain about 1.5 kg of body weight. This kind of farming is usually practiced for meat purpose using fast-growing varieties like *Vanaraja*, *Krishibro*, *Srinidhi*, *Kuroiler*, and Rainbow Rooster. About 10–20% of the backyard poultry is reared in this type of system, which is followed in areas like the North-Eastern states and Jammu & Kashmir.

Native chicken farming

Backyard poultry with indigenous/native chicken for meat purposes is the recently adopted business model, which has huge scope and potential in the coming years. Demand for meat and eggs from the native chicken breeds is increasing considerably both in urban and rural areas. The native chickens are slow growers. Typically, hens lay about 50–100 eggs in 1 year of production period with intermittent brooding phases. The birds are reared up to 3–5 months under intensive farming with a run area and complete ration. The birds fetch a premium price of up to Rs. 150–300 per kg based on the season. About 10–15% of the backyard produce comes from this system. The superiority in quality and composition of meat from Aseel, the most popular native chicken compared to commercial broiler meat, was demonstrated by Rajkumar et al. (2016a). Though the native chickens are slow growers and poor layers, they are ideal mothers and good sitters, excellent foragers, hardy, and naturally immune to common diseases (Haunshi et al. 2011; Padhi 2016; Rajkumar et al. 2017).

Breeding

The development of suitable chicken varieties with high productivity, better immunity, higher consumer acceptability, and efficiency to perform under the low plane of nutrition and management is the major objective of breeding for rural poultry. Generally, for genetic improvement, selective breeding in established indigenous breeds and crossbreeding with exotic lines or native breeds are the two popular methods followed for

the development of chicken varieties. Dana et al. (2010) reviewed the breeding objectives of village poultry and reported that egg and meat for household consumption were the two principal objectives of chicken rearing. Plumage color, comb pattern, and adaptability in terms of survivability, reproduction, and production traits were considered as the breeding goals in the development of backyard chicken varieties (Ayyagari 2001; Dana et al. 2010; Rajkumar et al. 2016b).

Selective breeding

Indigenous poultry breeds need to be characterized for growth and production traits before initiating the improvement of economic traits through selective breeding. Breeding for the improvement of indigenous chicken should focus on within-breed selection rather than crossbreeding to maintain the unique attributes of indigenous chicken, which are appreciated by consumers, farmers, and other stakeholders, and to avoid genetic erosion, and dilution. It was demonstrated that indigenous chicken can be improved for higher growth rate and egg production without losing other important characteristics like unique product qualities, adaptability, and disease resistance (Maki-Tanila 2007). Rajkumar et al. (2017) reported the annual production of 64 eggs in the Aseel breed without selection, which clearly shows the advantage of long-term selective breeding as demonstrated by Haunshi et al. (2019) in Aseel with 145 eggs in one laying cycle.

Though improvement through selection is slow in native chickens, the change in production will be permanent without compromising on the unique characteristics of native/indigenous breeds (Padhi 2016). The performance of indigenous breeds suitable for backyard poultry is presented in Table 1.

Crossbreeding

The crossbreeding strategy was quite successful in the improvement of productivity in rural poultry production as the results can be achieved in a shorter duration. It exploits the heterosis of the two lines involved in the cross and results in increased productivity. All the varieties thus developed are either two-way or three-way crosses, which are evolved by crossing improved germplasm (mediocre-colored broiler strains/lines) and native germplasm. Several dual-purpose breeds/crossbreds are available in India and other Asian countries. These have been bred exclusively to grow relatively fast and lay more eggs under the village backyard conditions. Crossbred hens lay approximately 140–200 eggs per year, while indigenous hens lay only 40 to 65 eggs per year (FAO 2004; Pym and Alders 2016; Rajkumar et al. 2017).

The limitation of this breeding approach is the segregation of genes that results in reduced productivity over the generations. The farmer has to depend constantly on the source of birds (company/institution) since self-propagation of the hybrids reduces the productivity. High yielding hybrids were highly successful in India and contributed significantly to the total poultry production in the country. In addition to the varieties developed in the past, a new dual-purpose variety has

Table 1 Indian native chicken breeds suitable for backyard poultry farming

Breed		Plumage	Bodyweight, g		Egg production, no.	Egg weight, g	Source
	Age, wks		Male	Female			
Aseel	20	Multicolored plumage with black glossy tail feathers	1841±20.7	1381±18.2			Rajkumar et al. (2017)
	40		2703±28.1	1704±23.2	18.0±1.0	37.1±0.3	Rajkumar et al. (2017)
	72		3794±20.8	2334±26.1	64.0±6.0	47.5±0.7	Rajkumar et al. (2017)
Aseel peela	20	Brown plumage with black glossy tail feathers		1382±22.2			Haunshi et al. (2011)
	40		2737±50.8	1832±25.8	36.2	49.3±0.5	Haunshi et al. (2011)
Kadaknath	20	Black-colored plumage		769.1±12.4			Haunshi et al. (2011)
	40		1740±30.9	1322±18.4	49.4	41.39±0.4	Haunshi et al. (2011)
	52				105	46.1±1.3	Mohan et al. (2008)
Ghagus	40	Brown plumage with black and white feathers	2537±46.9	1609±36.3	32.2	45.67±0.52	Haunshi et al. (2015a)
Ankleshwar	40	White and light grey to brown color with golden-colored tail feathers		1479±8.6	66.4±0.97	44.17±0.17	Patel et al. (2020)
Punjab Brown	72	Brown	2150±94	1570±40	60–80	46.0±1.9	Vij et al. (2006)
Tellicherry	72	Black and grey–colored	1620±16	1240±10	60–80	40.02±0.94	Vij et al. (2008)

been recently developed by this institute involving Cornish and Aseel inheritance with an annual production potential of 150 eggs and 1.4–1.5 kg (males) at 3 months of age (Rajkumar et al. 2019). Furthermore, a layer variety with a production potential of 180–190 eggs in a laying cycle of 72 weeks has also been developed (Rajkumar et al. 2018c). Some of the most popular and successful varieties developed and introduced through this approach in the country are listed in Table 2.

Selective breeding of parent lines for the traits of importance is an integral part of this crossbreeding to continually update the performance of the terminal cross (Haunshi et al. 2015b). Generally, male lines are selected for body weight, shank length, liveability, and immune response, while female lines are improved for egg production, and egg mass, persistency, etc.

Nutrition

Nutrition plays a major role in translating the genetic potential of the bird in terms of egg number and body weight. Balanced nutrition at a young age helps in the development of systems of the bird for the effective functioning of the metabolism. The nutrient requirement varies with the type of bird, genetic strain, body size, age, ambient temperature, physical activity, stressors, etc., which needs to be specified for optimum productivity. The feeding strategies being followed during chick/nursery and free-range foraging phases are discussed hereunder.

Nursery feeding

During the nursery period, chicks will be under a confinement system and hence balanced feed containing required

Table 2 Some of the popular crossbred varieties developed in India for backyard poultry farming

Variety	Purpose	Plumage	Bodyweight, kg			Annual egg production, no.		Reference
			10–15 wks	20 wks	40 wks	Farm	Backyard	
Vanaraja	Dual	Brown, black with black glossy tail feathers		2.09	2.6	150		Niranjan et al. (2008)
			1.2–1.5			160	110	Rajkumar et al. (2010)
			1.78	1.70	2.28		26 (40 wks)	Haunshi et al. (2009)
			1.5–2.0	1.24		140		Singh et al. (2018)
Gramapriya	Egg	Brown plumage	1.5	1.78	2.3	256		Rajkumar et al. (2018a)
			1.2–1.5			220	180	Rajkumar et al. (2010)
						220	160–180	Rajkumar and Rama Rao (2015)
Srinidhi	Dual	Multicolored with barred plumage	2.3	0.98		195		Singh et al. (2018)
			2.4			228	140–150	Rajkumar et al. (2018b)
Giriraja	Dual	Multicolored	1.6	1.4		140	125	Ramappa (2008)
Kuroiler	Dual	Thick reddish brown and barred feathers	0.77 (8 wks)	1.7	3.0		159	Islam et al. (2017)
Rainbow Rooster	Dual	Brownish red	0.71	1.65	2.8		163	Islam et al. (2017)
Nandanam	Dual			1.5			176	Chitra (2019)
Rajashri	Egg	Brown		1–1.2				Krishna et al. (2012)
Pratapdhan	Dual	Brown, whitish yellow feathers		1.6	2.2		165	Rajkumar et al. (2018b)
				1.75	2.15		159	Khadda et al. (2016)
Narmadanidhi	Dual	Black with whitish silk feathers	-	1.4	1.7	224	170	Rajkumar et al. (2018b)
Kamrupa	Dual	Brown and black		1.3–1.5	1.3–1.6	140–150	118–130	Rajkumar et al. (2018b)
Jharsim	Dual	Multicolored		1.6–1.8	-	165	110–130	Rajkumar et al. (2018b)
Himsamridhi	Dual	Brown		1.2	1.6	160	140	Rajkumar et al. (2018b)
CARI Nirbheek	Egg	Brown		1.7	2.2		167.9	Khadda et al. (2017)
Up-CARI	Egg	Brown frizzle feathers		1.22–1.3				Khan (2008)
CARI-Shyama	Egg	Black with silky white feathers		1.1–1.2				Khan (2008)

concentrations of metabolizable energy (ME), protein (CP), essential amino acids, macro- and microminerals, vitamins, and other essential feed additives should be provided to prevent the occurrence of nutritional deficiencies and ensure optimum growth as per the genetic potential of the variety of chicken.

Based on the data generated from a series of trials conducted at the institute on the BYPF varieties (1–42 days of age), the requirement of major nutrients, i.e., ME (2400 kcal/kg) and CP (16.0%), was less by about 18.6 (Rama Rao et al. 2005) and 28.9% (Rama Rao et al. 2006a) compared to the commercial broiler chicks during the pre-starter phase. The dietary CP levels can be further reduced to 14.5% by increasing the total sulfur amino acids to 0.57% in the diets of BYPF chicken varieties (Rama Rao et al. 2007a, 2010). The performance and bone mineral variables of Vanaraja chicken (day 1 to 42 days) were optimum with diets containing 0.7 and 0.35% Ca and NPP, respectively (Rama Rao et al. 2007b).

For the meat type colored birds meant for backyard/small-scale intensive system, marginal reduction (−10%) of CP in the diet by maintaining normal levels of lysine (1.1 and 1.0%) and total sulfur containing amino acids (0.9 and 0.72%) during starter and finisher phases or 10% reduction in total sulfur containing amino acids was found optimum (Raju et al. 2012). Dietary energy of 2750 and 2800 kcal of ME/kg with corresponding CP content of 21.2 and 19.2% were found optimum for *Krishibro* (colored broiler) chicks during starter and finisher phases, respectively (Panda et al. 2008). Furthermore, the cost of feed required to produce 1 kg live weight gain in *Krishibro* could be considerably reduced by replacing maize with sorghum or pearl millet as the principal sources of energy (Rama Rao et al. 2002).

In general, the chicks of BYPF varieties require about 2400–2500 kcal ME, 16% protein, 0.77% lysine, 0.36% methionine, 0.35% available phosphorus, and 0.7% calcium. Farmers can buy commercially available feed (layer chick feed) or prepare their own feed with the locally available ingredients as shown in Table 3.

In addition to the chickens developed for BYPF, their parents also need energy restriction during the growing phase, which was found beneficial in the female parent line of Krishibro (Sunder et al. 2008). The female parent breeders of Gramapriya showed better egg production and feed conversion efficiency when the nutrient density of the diet was increased to 102.5% of the normal levels (Prakash et al. 2019a). Dietary concentration of 0.68% lysine, 0.3% methionine, and 0.46% threonine was found optimum for Gramapriya female parent breeders (*Dahlem Red*) when they were fed moderately lower protein based diets (Prakash et al. 2019b).

Feeding in free-range conditions

The birds are left for scavenging in rural/tribal backyards after 4–6 weeks of age. The success and sustainability of free-range poultry farming depend on the quantity and composition of the natural feed base available in village backyards and also the ability of the farmers to provide supplementary feeding. Generally, backyard chickens scavenge for feed for about 6–11 h during day time (Maphosa et al. 2004). As the availability of natural feed base is not uniform across the seasons and regions, the majority of farmers provide supplementary feeding with locally available feed or household cereal grains/kitchen offals to meet the nutrient requirement of the bird. Goromela et al. (2008) reported that the backyard free-range chickens grew on scavenging conditions consumed daily 45 to 54 g of feed (natural food base) in different seasons, which was insufficient to meet the protein and energy requirements of the birds. It is very difficult for the birds to perform to their potential under the sub-optimal nutrition making the supplementary feeding essential for optimum productivity in a free-range system.

Different birds/varieties require different amounts of nutrients, depending on the production stage and metabolic requirements. Therefore, it is always a big question whether a bird gets enough nutrients under free-range system or not. Shortage of protein in scavenging is not a major constraint as the availability of insects is abundant in the majority of backyards. Energy is considered the major limiting nutrient in the scavenging system, which needs to be supplemented through locally available energy rich ingredients like corn, broken rice, sorghum, and millets. About 80–90% of farmers provide supplementary feeding in most of the African countries (Dana et al. 2010), which is also common in India.

Table 3 Approximate quantities of feed ingredients and additives for preparation of feed for BYPF chicken varieties during nursery phase (1–42 days)

Ingredients	kg/100 kg feed
Maize/pearl millet/finger millet/broken rice etc.	50
Rice bran/wheat bran/de-oiled rice bran etc.	20
Soybean meal/groundnut meal/sunflower meal/sesame cake/linseed cake/mustard cake/distillery dried grain with solubles etc. (a combination of more than two would be ideal)	28
Vitamin and mineral mixture	2 parts

However, the degree of supplementation varies with the availability of resources.

The natural food base comprises of insects, fallen grains, greens, kitchen offal, stone, etc., which largely depends on geographic region, climate variables (rainfall, humidity), season, food habits of humans, etc. It is important to know the composition and quantity of the natural food base available for chickens in backyards, which will form the basis to decide the quantity and quality of supplementary feed. The quality of egg and chicken meat from native and backyard chicken was studied extensively (Rajkumar et al. 2016a, b, 2020b). The safety aspect of poultry produce from the backyard poultry is a probable concern that has not been studied; however, there is no report or study on the adverse effect of backyard poultry produce on human health. An extensive study was conducted at the authors' institute to find out the quantity and nutritional profile of the natural food base available in 4 different agro-climatic regions (tropical, humid subtropical, cool-temperate, and semi-arid) of India (Prakash et al. 2020). Contents of crop and gizzard were analyzed to assess the nutritional status of the backyard chickens. The data indicated considerable variation in the availability of energy, protein, Ca, and P in different regions. The deficiency of energy, protein, Ca, and P ranged between 9 and 20, 40 and 50, 42 and 66, and 72 and 83%, respectively, in different regions. This wide variation among regions makes it imperative to develop region-specific supplementary feeding strategies.

As the cost of feed is escalating over the past few years, preparation of diets for backyard poultry with various alternate energy (broken rice, pearl millet, finger millet, foxtail millet, sorghum, etc.) and protein (sunflower, sesame, cottonseed, guar meal, etc.) sources as available in different regions would help to keep the cost of supplementary feed low. Earlier reports from this institute also suggested the possibility of inclusion of different alternative energy sources like sorghum (Rama Rao et al. 1995) and millets (Raju et al. 2004), and protein sources like sesame meal (Rama Rao et al. 2008), sunflower meal (Rama Rao et al. 2006b), cottonseed meal (Rama Rao et al. 2016), and guar meal (Rama Rao et al. 2014), which can be included in the chicken diet at different inclusion levels. Since the growth of backyard chicken varieties is slow and the requirement of ME and CP is relatively low, these alternate feed ingredients can be safely included in their diets either during the nursery or free-range phase without affecting the performance.

Supplementation of commercial vitamin and trace mineral premix along with household cereal grains would reduce the incidence of nutritional deficiencies, particularly during free-range conditions. As the requirement of Ca is high for eggshell formation, additional supplementation of Ca source (stone grit, shell grit, marble chips, etc.) would improve the shell quality besides preventing the leg weakness problem in layers under BYPF.

Housing

Backyard poultry needs proper housing in the form of night shelter for protection from predators and adverse weather conditions. The size and type of night shelter vary largely with the availability of resources and flock size. The typical poultry house is usually made with locally available materials like wood, bamboo, granite, mud, and thatched roof in India. Small-scale and intensive farm owners prefer poultry shed with asbestos roof, concrete walls, and a wire mesh for crossventilation. Both fixed and movable temporary poultry houses are commonly used in BYPF systems. Ideally, a bird should have floor space of 1 sft during the growing phase and about 2–2.5 sft during the laying phase for proper movement in the night shelter.

Health management

Health management in poultry farms depends on biosecurity and proper vaccination. In the backyard system, maintaining proper biosecurity like in a commercial system is a big challenge. A pragmatic way is to immunize the birds with vaccination, which is again a constraint under the scavenging system. Veterinary services, vaccination, health management, and predator attack were some of the constraints experienced by the BYPF farmers in India (Rajkumar et al. 2010; Rajkumar and Rama Rao 2015) and in Africa (Sambo et al. 2015), which were common across the globe. The common diseases prevalent in BYPF are Newcastle disease (ND) and fowlpox (FP), particularly in the hot and humid coastal regions for which periodic vaccination with local strains is advocated globally. The birds are exposed to a high degree of pathogen load under free-range scavenging conditions and need to be monitored for health disorders regularly. Considering the obvious limitations, it is recommended to practice mass/community vaccination with the help of NGOs, para vets, and other line departments for effective control of viral diseases. Similarly, to minimize the spread of diseases, village-/community-based bio-security and health management programs were successful in controlling the diseases and protecting the village poultry systems in Indonesia (FAO 2010; ACIAR 2010).

ND control under backyard conditions through the training of community vaccinators was proved effective in Sub-Saharan Africa (Alders et al. 2010, 2018). The availability of a thermostable vaccine for ND has greatly reduced the adverse effect of the disease in BYPF (Alders and Pym 2009). However, the birds are exposed to many other pathogens such as avian influenza, fowl pox, infectious bronchitis, infectious bursal disease, and Marek's disease that can cause significant mortality and morbidity (Alders et al. 2018), which need to be monitored regularly to prevent the losses. Bacterial

diseases may also have a significant impact on the health and productivity of birds, which can be prevented by proper biosecurity and customized treatment.

Another major health challenge in BYPF is the parasitic (both external and internal) infestation due to constant exposure to the contaminated feed and water. Therefore, periodic mass de-worming is practiced at 6 monthly intervals to reduce internal parasites. It is a regular practice in India to offer deworming medicine a week before ND vaccination to improve immune response, besides cleaning the intestine. Infestation with internal parasites and bacterial pathogens can be largely minimized by providing fresh drinking water during the early hours before the birds leave for scavenging. The water, mostly from sewerage in the backyards is the potential source of parasites like nematodes, cestodes, and trematodes, which infect the poultry (Calnek et al. 1991) and cause substantial losses to the farmers. External parasitic infestation from lice, flies, fleas, bugs, and mites is very common in night shelters or poultry houses with a moist wet floor and poor ventilation (Calnek et al. 1991). Keeping the poultry houses dry with proper cross ventilation minimizes the risk of external parasites.

Inadequate surveillance, under-reporting, and improper records of poultry diseases remain the primary concerns in many countries across the globe (Alders 2012) including India. Proper database of prevailing diseases and their accurate reporting and documentation aids in formulating the disease control strategies for various diseases, which need to be taken up on a priority basis. Summary of reports of OIE from 2005–2010 on poultry diseases across five countries (Brazil, Egypt, Indonesia, Nigeria, and Thailand) suggests that surveillance for poultry diseases remains a big challenge (Alders 2012), which is true in India also.

Marketing

Marketing is one of the major problems faced by the rural poultry farmers. The feedback and our experience from the field reveal that there is no organized marketing channel for effective disposal of eggs and birds from BYPF. Marketing is vital for the success and sustainability of the BYPF. The creation of marketing channels through self-help groups or a cooperative model of marketing will help the farmers in marketing their produce. Creating suitable marketing opportunities will lead to the sustainability of rural poultry farming in India.

Economics

The BYPF is largely a subsidiary income generating activity for the family in the country rather than the main source of income. Three farming systems, viz., traditional, semi-intensive, and native chicken farming, being practiced in India fall under the subsidiary income sources category, while small-scale intensive system aims at substantial income generation. *Vanaraja* chicken farming was profitable compared to the native chickens with 46.78% more net returns from a unit of 20 birds with a benefit-cost ratio of 2.84 (Baruah and Raghav 2017) from Arunachal Pradesh, India. A total of Rs. 10,578 was earned as the net income from a unit of 20 *Vanaraja* birds with a net profit of Rs. 529/ bird (Baruah and Raghav 2017). The economics of *Vanarja* (Rajkumar et al. 2010, 2018b) and *Gramapriya* (Rajkumar and Rama Rao 2015; Rajkumar et al. 2018b) in a traditional backyard system was estimated with the net profit per pair of birds (cock and hen) as Rs. 595–705 for *Vanaraja* and Rs. 820–930 for *Gramapriya* chicken, respectively. The average net returns from a unit of 20 birds were about Rs. 5200 from *Vanaraja* and about Rs.7000 from *Gramapriya* rearing (Rajkumar et al. 2018b) by considering the minimum price for the egg and chicken meat.

The impact of backyard poultry is not only limited to income earning but also to provide nutritional security in most of the underdeveloped and developing countries. Backyard poultry has the potential to reduce the malnutrition in the rural areas across the world. The visible impact of backyard poultry was noticed in North-Eastern hilly regions and remote backward tribal regions of India. The detailed input and output costs of Vanaraja published earlier by Rajkumar et al. (2018b) are presented in Table 4.

Conclusions

The BYPF has a huge potential in enhancing the availability of egg and chicken meat in the rural and tribal areas, besides generating employment and a supplementary income, and empowering women, etc. A few of the major challenges for BYPF are maintenance of biosecurity, emerging and re-emerging diseases, nutrient deficiencies, predation, marketing, and erosion of indigenous breeds. But all these challenges offer opportunities to overcome the constraints to move forward with sustainable production. Community-based models in health care, marketing, and skill development are the best approaches to reap the maximum benefits from the BYPF. The premium price and huge demand for the free-range eggs and meat is another asset of BYPF, which is going to increase further in the future.

The high-yielding improved chicken varieties revolutionized the BYPF in terms of productivity and economic returns, though they pose threat to the existence of indigenous chicken breeds. The breeding policy of Govt. of India and ICAR envisages avoiding the introduction of the improved varieties in the home tracts of the recognized chicken breeds, which will prevent the genetic erosion of native breeds.

Table 4 Economics of Vanaraja bird under free-range conditions per pair of male and female (Source: Rajkumar et al. 2018b)

Input			Output		
Sex	Age of the bird	Cost (Rs)*	Particulars/details of the bird	Receipt (Rs)	Profit (Rs)
Male	12wks	100	Bird at 12wks (1.5–1.8 kg) @ Rs. 120/kg	180–240	80–140
Female	72wks	225	Eggs: 100–110 @ Rs. 5/egg	500–550	515–565
			Birds: 3.0 kg @ Rs. 80 kg	240	
			Total	740–790	
Total profit from a pair of birds		325		920–1030	595–705

*Includes cost of day-old chick, feed, medicines, healthcare, etc

Author contributions All authors contributed in conceptualization of the article. The first author prepared the manuscript reviewing all aspects of backyard poultry farming in India. Dr. Rama Rao added and supplemented the information on nutrition. Dr. M. V. L. N. Raju critically reviewed and edited the article and improved the article. D. Chatterjee edited the article. All have contributed in improving the article.

Funding The institute research project was funded by Institute fund of Indian Council of Agricultural Research- Directorate of Poultry Research, Hyderabad.

Data availability NA. It is a review article.

Code availability Not applicable

Declarations

Ethics approval The project was approved by the Institute Animal Ethics Committee (IAEC/DPR/17/4). The manuscript does not contain clinical studies and patient data.

Conflict of interest The authors declare no competing interests.

References

ACIAR., 2010. Cost-effective biosecurity for non-industrial commercial poultry operations in Indonesia. Annual Report June 2009 to May 2010. Australian Centre for International Agricultural Research, Canberra.

Alders, R. G., 2012. Challenges and opportunities for small-scale family poultry production in developing countries. XXIV World's Poultry Congress, Salvador, Brazil, 5-9 August, 2012. World's Poultry Science Journal, 68, (Suppl.1):153.

Alders, R. G., and Pym, R. A. E., 2009. Village poultry: Still important to millions, eight thousand years after domestication. World's Poultry Science Journal, 65 (02), 181-190.

Alders, R. G., Bagnol, B., and Young, M. P., 2010. Technically sound and sustainable Newcastle disease control in village chickens: Lessons learnt over fifteen years. World's Poultry Science Journal, 66, 433–440.

Alders, R.G., Dumas, S.E., Rukambile, E., Magoke, G., Maulaga, W., Jong, J., and Costa, R. 2018. Family poultry: Multiple roles, systems, challenges, and options for sustainable contributions to household nutrition security through a planetary health lens. Maternal and Chie12668ld Nutrition, 14 (Suppl 3). https://doi.org/10.1111/mcn.12668.

Ayyagari, V., 2001. Development of varieties for rural poultry. In: Souvenir on Sustainable Poultry production: Rural and commercial approach. 3rd March, Hyderabad, India, pp. 7-14.

BAHS., 2019. Basic Animal Husbandry Statistics. Department of Animal Husbandry and Dairying. Ministry of Fisheries, Animal Husbandry and Dairying, Government of India.

Baruah, M. S., and Raghav, C. S. 2017. Viability and economics of backyard poultry farming in West Siang district of Arunachal Pradesh, India. International Journal of Food, Agriculture and Veterinary Sciences. 2017 Vol.7 (1) January-April, pp. 9-14. http://www.cibtech.org/jfav.htm.

Calnek, B.W., Barnes, H.J., Beard, C.W., Reid, W.M., and Yoder Jr., H.W., 1991. Diseases of Poultry, 9th edition. Iowa state University press, Ames, Iowa.

Chatterjee, R.N., and Rajkumar, U., 2015. An overview of poultry production in India. Indian Journal of Animal Health, 54(2), 89-108.

Chitra, P., 2019. Comparative study of Nandanam chicken IV (Rhodo White chicken) and desi chicken rearing under backyard system in rural areas of Salem district of Tamil Nadu. International Journal of Science and Environment Technology, 8, 1049-1053.

Crawford, R. D., 1990. "Origin and History of Poultry Species." In Poultry Breeding and Genetics; Edited by R. D. Crawford, 1–42. New York: Elsevier.

Dana, N., van der Waaij, L.H., Dessie, T., and van Aredonk, J. A. M., 2010. Production objectives and trait preferences of village poultry producers of Ethiopia: implications for designing breeding schemes utilizing indigenous chicken genetic resources. Tropical Animal Health and Production, 42, 1519-1529. https://doi.org/10.1007/s11250-010-9602-6

FAO., 2004. Small-scale poultry production: technical guide In FAO animal production and health manual #1. Rome: Food and Agriculture Organization of the United Nations; Available: http://www.fao.org/docrep/008/y5169e/y5169e00.htm

FAO., 2007. Poultry proceedings of the International Conference Poultry in the Twenty-first Century: avian influenza and beyond, held 5–7 November 2007, Bangkok, Thailand. Rome.

FAO., 2010. Chicken genetic resources used in smallholder production systems and opportunities for their development, by P. Sørensen. FAO Smallholder Poultry Production Paper, No. 5. Rome.

FAO., 2014. Decision tools for family poultry development FAO Animal Production and Health Guidelines, No. 16 Rome, Italy

Goromela, E.H., Kwakkel, R.P., Verstegen, M.W.A., and Katule, A. M., 2008. Effect of season and farming system on the quantity and nutritional quality of scavengeable feed resources and performance

of village poultry in central Tanzania. Journal of Cell and Animal Biology, 2(3), 063-071.

Haunshi, S., Doley, S., and Shakuntala, I., 2009. Production performance of indigenous chicken of northeastern region and improved varieties developed for backyard farming. Indian Journal of Animal Sciences, 79 (9), 901-905.

Haunshi, S., Niranjan, M., Shanmugam, M., Padhi, M. K., Reddy, M. R., Sunitha, R., Rajkumar, U., and Panda, A.K., 2011. Characterization of two Indian native chicken breeds for production, egg and semen quality, and welfare traits. Poultry Science, 90, 314-320.

Haunshi, S., Shanmugam, M., Rajkumar, U., Padhi, M. K., and Niranjan, M., 2015a. Characterization of Ghagus breed vis-a-vis PD–4 birds for production, adaptability, semen and egg quality traits. Indian Journal of Animal Sciences, 85 (12), 1338-1342.

Haunshi, S., Reddy, B.L.N., Niranjan, M., Rajkumar, U., Padhi, M. K., Raja, K.S.R., and Chatterjee, R.N., 2015b. Status of genetic resources of chicken evolved at ICAR, DPR, Hyderabad. Pp 1-101.

Haunshi, S., Rajkumar, U., and PADHI. M. K., 2019. Improvement of PD-4 (Aseel), an indigenous chicken, for growth and production traits. Indian Journal of Animal Sciences, 89(4), 419 - 423

Islam, R., Deka C.K., Rahman, M., Deka, B.C., Hussain, M., and Paul, A., 2017. Comparative performances of Kuroiler, Raibow Rooster and Indigenous birds under backyard system of rearing in Dhubri district of Assam. The Journal of Rural and Agricultural Research, 17, 40-43.

Islam, R., Sapcota, D., Saikia, A.K., and Sheikh, I.U., 2020. Performances of Improved Dual Type Backyard Chicken in Free Range System: A Review. Journal of Poultry Science and Technology, 8 (2), 32-40.

Khadda B.S., Lata, K., Kumar, R., Kaushal, S., and SHARMA, R.K., 2016. Performance of Pratapdhan chickens under field condition of semi-arid ecosystem in central Gujarat. Indian Journal of Poultry Science, 51(1), 79-83.

Khadda B.S., Lata, K., Kumar, R., Jadav, J.K., Singh, B., and Palod, J., 2017. Production performance and economics of CARI Nirbheek chicken for backyard farming under semi-arid ecosystem in central Gujarat, India. Indian Journal of Animal Research, 51, 382-386.

Khan, A.G., 2008. Indigenous breeds, crossbreds and synthetic hybrids with modified genetic and economic profiles for rural family and small scale poultry farming in India. World's Poultry Science Journal, 64, 405-415.

Krishna, D., Rama Rao, S.V., PRAKASH, B., and Preetham, V. C., 2012. Growth Performance and Survivability of Rajasree Birds under Deep Litter and Scavenging Systems. International Journal of Poultry Science, 11 (10), 621-623, 2012

Maki-Tanila, A., 2007. Animal breeding further ameliorated. Journal of Animal Breeding and Genetics, 124, 1-2

Maphosa, T., Kusina, J. F., Kusina, N.T., Makuza, S., and Sibanda, S., 2004. A monitoring study comparing production of village chickens between communal (Nharira) and small-scale commercial (Lancashire) farming areas in Zimbabwe. Livestock Research for Rural Development, 16 (7). http://www.cipav.org.co/lrrd/lrrd16/7/maph16048.htm.

Mapiye, C. M., Wale, M., Mupangwa, J. F., Chimonyo, M., Foti R., and Mutenje, M. J., 2008. A research review of village chicken production constraints and opportunities in Zimbabwe. Asian-Australasian Journal of Animal Sciences, 21: 1680 – 1688.

Mohan, J., Sastry, K. V. H., Moudgal, R. P., and Tyagi, J. S., 2008. Production and other characteristics of Aseel Peela desi hens under normal rearing system. Indian Journal of Poultry Science, 43, 217–219.

Niranjan, M., Sharma, R.P., Rajkumar, U., Reddy, B.L.N., Chatterjee, R.N., and Bhattacharya, T.K., 2008. Comparative evaluation of production performance in improved chicken varieties for backyard farming. International Journal of Poultry Sciences, 7, 1126-1131.

Padhi, M.K., 2016. Importance of Indigenous breeds of chicken for rural economy and their improvements for higher production performance. Scientifica, https://doi.org/10.1155/2016/2604685

Panda, A.K., Rama Rao, S.V., Raju, M.V.L.N., and Reddy, B.L.N., 2008. Growth, immune competence and carcass characteristics of broiler chicken (Krishibro) to concentrations of dietary energy maintained at constant ME:CP ratio. Indian Journal of Animal Sciences, 78 (8), 878-881.

Patel, A.B., Bhagora, N.J., Savaliya, F.P., Mishra, R.K., and Lonkar, V.D., 2020. Performance of Ankleshwar Chicken Reared under Intensive Management System in Gujarat. Indian Journal of Veterinary Science and Biotechnology, https://doi.org/10.21887/ijvsbt.15.4.9

Prakash, B., Rama Rao, S.V., Raju, M.V.L.N., Verma, S.K., and Panda, A.K., 2019a. Effect of varying nutrient density of diets on productive performance in Dahlem Red layers. Indian Journal of Animal Nutrition, 36 (3), 286-289.

Prakash, B., Rama Rao, S.V., Raju, M.V.L.N., Verma, S.K., 2019b. Effect of different levels of amino acids in low protein diets on egg production, anti-oxidant response and immune parameters in Dahlem Red Layers. Indian Journal of Animal Research, 53(1), 45-48.

Prakash, B., Verma, S.K., Rama Rao, S.V., Raju, M.V.L.N., Paul, S.S., Kannan, A., Mishra, S., Singh, V., and Sankhyan, V., 2020. Feeding status of free-range scavenging chickens in different agro-climatic regions of India. British Poultry Science, 61 (1), 26-32. https://doi.org/10.1080/00071668.2019.1671956

Pym, R., and Alders, R., 2016. Helping smallholders to improve poultry production. In: Achieving sustainable production of poultry meat, (pp. 441–471). Cambridge, UK: Burleigh Dodds Science Publishing.

Rajkumar, U., and Rama Rao, S. V., 2015. Gramapriya, a prolific brown egg layer for rural backyards. Indian Farming, 65, 32-34.

Rajkumar, U., Rama Rao, S.V., and Sharma, R.P., 2010. Backyard poultry farming: Changing the face of rural India. Indian Farming, 59, 20-23. 2010.

Rajkumar, U., Muthukumar, M., Haunshi, S., Niranjan, M., Raju, M.V.L.N., Rama Rao, S.V., and Chatterjee, R.N., 2016a. Comparative evaluation of carcass traits and meat quality in native Aseel chickens and commercial broilers. British Poultry Science, 57, 339-347.

Rajkumar, U., Padhi, M.K., Haunshi, S., and Chatterjee, R N., 2016b. Genetic and phenotypic response in Vanaraja male line chicken under short term selection experiment. Indian Journal of Animal Sciences, 86 (11), 1287-1290.

Rajkumar, U., Haunshi, S., Paswan, C., Raju, M.V.L.N., Rama Rao, S.V., and Chatterjee, R.N., 2017. Characterization of indigenous Aseel chicken breed for morphological, growth, production and meat Composition traits from India. Poultry Science, 96, 2120-2126.

Rajkumar, U., Paswan, C., Haunshi, S., and Niranjan, M., 2018a. Evaluation of terminal crosses to assess the suitability of PD-6 line as a male line for Gramapriya chicken variety developed for rural poultry. Indian Journal of Animal Sciences, 88 (4), 438–442.

Rajkumar, U., S. V. Rama Rao, and Chatterjee, R.N., 2018b. Improved chicken varieties. ICAR-DPR Publication, Pp. 1-42.

Rajkumar, U., Haunshi, S., Paswan, C., and Reddy, B.L.N., 2018c. Evaluation of three way crossbred chicken developed for rural poultry under farm and backyard conditions for growth and production traits. Indian Journal of Animal Sciences, 88, 229-232.

Rajkumar, U., Haunshi, S., Paswan, C., Prakash, B., Padhi, M.K., and Rama Rao, S. V., 2019. Evaluation of two way cross developed for free range poultry farming under farm and free range conditions. Indian Journal of Animal Sciences, 89 (6), 652-657.

Rajkumar, U., Prince, L.L.L., Paswan, C., Haunshi, S. and Chatterjee, R.N., 2020a. Variance component analysis of growth and production traits in Vanaraja male line chicken using animal model. Animal

Biosciences (Asian-Australasian Journal of Animal Sciences) https://doi.org/10.5713/ajas.19.0826.

Rajkumar, U., Prince, L.L.L., Haunshi, S., Paswan, C. and Muthukumar, M. 2020b. Evaluation of Growth, Carcass and Meat Quality of a Two-way Cross Developed for Rural Poultry Farming. Indian Journal of Animal Research. https://doi.org/10.18805/ijar.B-3990

Raju, M.V.L.N., Shyam Sunder, G., Sadagopan, V.R., Elangovan, A.V., Reddy, M.R., and Rama Rao, S.V., 2004. Replacement of maize with jowar, bajra or ragi in broiler chicken diets. Animal Nutrition and Feed Technology, 4, 53-61.

Raju, M.V.L.N., Panda, A.K., Rama Rao, S.V., Devi, K.R.V.N., and Shyam Sunder, G., 2012. Effect of varied dietary concentration of protein and critical amino acids on multicolored broiler chickens. Indian Journal of Animal Nutrition, 29 (3), 297-301.

Rama Rao, S.V., Praharaj, N.K., Raju, M.V.L.N., Mohapatra, S.C., Chawak, M. M., and Mishra, S.K., 1995. Replacement of yellow maize with tannin free sorghum in White Leghorn layer diet. Indian Journal of Poultry Science, 30, 76-78.

Rama Rao, S.V., Shyam Sunder, G., Panda, A.K., Reddy, M.R., Raju, M.V.L.N., and Praharaj, N.K., 2002. Utilization of different millets replacing maize in coloured broiler chicken diet. Indian Journal of Animal Nutrition, 19(4), 353-358.

Rama Rao, S.V., Panda, A.K., Raju, M.V.L.N., Shyam Sunder, G., Bhanja, S.K., and Sharma, R.P., 2005. Performance of Vanaraja chicken on diets containing different concentrations of metabolizable energy at constant ratio with other essential nutrients during juvenile phase. Indian Journal of Poultry Science, 40, 245-248.

Rama Rao, S.V., Panda, A.K., Raju, M.V.L.N., Sharma, S.R., Shyam Sunder, G., and Sharma, R.P., 2006a. Performance of Vanaraja chicks fed diets containing different levels of protein. Indian Journal of Animal Nutrition, 23(2), 83-87.

Rama Rao, S.V., Raju, M.V.L.N., Panda, A.K., and Reddy, M.R., 2006b. Sunflower seed meal as a substitute for soybean meal in commercial broiler chicken diets. British Poultry Science, 47, 592-598.

Rama Rao, S.V., Panda, A.K., Raju, M.V.L.N., and Poonam, N.S., 2007a. Effect of dietary methionine concentration on performance of Vanaraja chicks. Animal Nutrition and Feed Technology, 7, 241-246.

Rama Rao, S.V., Panda, A.K., Raju, M.V.L.N., Reddy, M.R., Saharia, P. N., Shyam Sunder, G., and Sharma, R.P., 2007b. Performance and bone mineralization in Vanaraja chicks fed different concentrations of calcium and non-phytate phosphorus. Indian Journal of Poultry Science, 42, 31-36.

Rama Rao, S.V., Raju, M.V.L.N., Panda, A.K., Poonam, N.S., Shyam Sunder, G., and Sharma, R.P., 2008. Utilization of sesame (Sesamum indicum) seed meal in broiler chicken diets. British Poultry Science, 49, 81-85.

Rama Rao, S.V., Panda, A.K., Raju, M.V.L.N., Shyam Sunder, G., and Sharma, R.P., 2010 Interaction between dietary protein and critical amino acids on performance of birds developed for free range farming during juvenile stage. Indian Journal of Animal Sciences, 80, 565-569.

Rama Rao, S.V., Prakash, B., Raju, M.V.L.N., Panda, A.K., and Murthy, O.K., 2014. Effect of supplementing non-starch polysaccharide hydrolyzing enzymes in guar meal based diets on performance, carcass variables and bone mineralization in Vanaraja chickens. Animal Feed Science and Technology, 188, 85-91.

Rama Rao, S. V., Nagaraja kumari, K., Raju, M. V. L. N., and Panda, A. K., 2016. Utilization of decorticated low gossypol cotton seed meal in WL layer diets. Indian Journal of Poultry Science, 51, 65-69.

Ramappa, B.S., 2001. Development of varieties for rural poultry. In: Souvenir on Sustainable Poultry production: Rural and commercial approach. 3rd March, Hyderabad, India, pp. 1-6.

Sambo, E., Bettridge, J. Dessie, T., Amare, A., Habte, T., Wigley, P., and Christley, R. M., 2015. Participatory evaluation of chicken health and production constraints in Ethiopia. Preventive Veterinary Medicine, 118, 117–127.

Sharma, R.P., and Chatterjee, R.N., 2009. Backyard poultry farming and rural food security. Indian Farming, 59, 36-37.

Sheikh, I.U., Nissa, S.S., Zaffer, B., Akand, A.H., Bulbul, K.H., Hasin, D., Hussain, I., and Hussain, S.A., 2018. Propagation of backyard poultry farming for nutritional security in rural areas. International Journal of Veterinary Sciences and Animal Husbandry, 3(4), 03-06.

Singh, M., Mollier, R.T., Rajesha, G., Nguillie, A.M., Rajkhowa, D. J., Rajkumar, U., Paswan, C., and Chatterjee, R. N., 2018. Backyard poultry farming with Vanaraja and Srinidhi:proven technology for doubling the tribal farmers' income in Nagaland. Indian Farming. 68(01), 80-82.

Sunder, G.S., Vijaya Kumar, C.H., Panda, A.K., Rama Rao, S.V., Raju, M.V.L.N., and Reddy, M.R., 2008. Energy restriction in broiler breeders during rearing and laying periods and its influence on body weight gain, conversion efficiency of nutrients, egg production and hatchability. The Journal of Poultry Science, 45, 273-280.

Vij, P., Tantia, M., and Vijh, R.K., 2006. Characterization of Punjab Brown chicken. Animal Genetic Resources Information, 39, 65-76. https://doi.org/10.1017/S1014233900002145.

Vij, P., Tantia, M., Anil Kumar, K., and Vijh, R. K., 2008. Phenotypic and genetic characteristics of Tellichery breed of chicken. Indian Journal of Animal Sciences, 78 (12), 1420-1422.

West, B., and Zhou, B.X., 1988. Did chickens go north? New evidence for domestication, Journal of Archaeological Science, 15, 515-533.

Zeuner, F.E., 1963. A history of domesticated animals, Hutchinson & Co, London, pp 560.