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Original Article

An Assessment of Chemical and Microbiological Properties of Different Types of Poultry Waste Compost Prepared by Bin and Windrow Composting System

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Bin, Chemical, Composting, Microbiological, Poultry Waste, Windrow.

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ABSTRACT

The present study aimed to evaluate the physical, chemical, and microbiological characteristics of 4 different poultry waste (dead birds, hatchery waste, offal, and a mixture of all) processed under two composting systems (bin and windrow). For this purpose, 12 compost bins and 12 windrow piles having different poultry waste were placed according to 2 × 4 factorial arrangements under Completely Randomized Design. Treatments consisted of 2 composting systems (bin and windrow) and 4 compost types (dead birds, offal, hatchery waste, and a mixture of all). The bins were comprised of 3 compartments (primary, secondary, and curing) and filled with dead birds, offal, hatchery waste, and a mixture of all. A similar procedure was adopted for the windrow composting system. Samples from each experimental material were collected and analyzed for proximate, amino acid, mineral, and bacterial analysis during the initial and curing phase. Results revealed that the highest crude protein (CP) content was found in dead birds while the lowest in hatchery waste compost processed under both composting systems. The highest temperature was recorded in dead bird's compost during the primary phase while the minimum was found in hatchery waste. Microbial count of salmonella, mycoplasma, *E. coli,* and total plate count was found minimum in all types of compost. Macrominerals like Na, K, and P were the highest in dead birds while the lowest in hatchery waste compost. It can be concluded that dead birds compost processed through bin composting system had ideal proximate composition having minimal pathogenic load with superior amino acid and mineral profile as compared to other waste materials.

INTRODUCTION

The poultry sector is one of the most organized, fastest-growing, and vibrant segments of the agriculture industry in Pakistan. During the past few decades, the poultry industry has seen overwhelming progress in commercial broiler houses and an increased number of hatcheries to fulfill day old chick demand of these houses (Ahmad, 2008). Although this progression is essential to cater to the need of our mushrooming population it also comes up with the production of a huge amount of poultry wastes i.e., dead birds, poultry bedding, offals, and hatchery wastes. In Pakistan, the broiler population is around 1.404 billion/annum having 4-5 % average mortality (ESP, 2019) during rearing resulting in the production of 48 million kg or 48M ton/annum dead birds (PPA, 2020). The situation becomes worse in case of any viral disease outbreak like New Castle Disease (ND) or Avian Influenza (AI) and mortality (%) may climb up to 50- 75% (PPA, 2019). These dead birds are the potential threat of disease spread, so their safe disposal is a big challenge in the current scenario. To obtain 1.404 billion DOC's 1.7 billion hatchable eggs are also set in hatcheries which may produce 18 million kg hatchery waste per year (PPA, 2019). Moreover, the huge amount of visceral organ waste is also produced when these broilers are slaughtered at a commercial scale (Ferreira, 2018). These mammoth poultry waste materials may pose serious health risks if not disposed-off properly.

All over the world, different methods are used for proper disposal of poultry wastes (mortality, visceral organs, and hatchery wastes) including incineration, burial, rendering, and composting, each having some advantages and disadvantages. Incineration is not environment friendly and costly as highly efficient incinerators are required for proper disposal of wastes (Blake & Donald, 2002). The burial method promotes pathogens and other harmful components of poultry by-products that contaminate the underground water by decomposition and deteriorate soil quality (Wood *et al.,* 2010; Calleja-Cervantes *et al.,* 2015). Through composting, these massive poultry wastes can be disposed-off properly into highly enriched end products along with a reduction in environmental risks.

Composting is a natural process that takes place under aerobic and thermophilic conditions (Khan, 2019). Among the various methods adopted to carry out the composting process, bin and windrow composting are the most common methods and viable at the farm level (Malone, 2004). Bin composting can be performed at a small scale in a small bin having 3 compartments (primary, secondary, and curing) without much hustle, but due to small, larger quantities of poultry wastes cannot be composted using bin composting method (Bukhari *et al.,* 2017). Windrow composting method is also common and mostly adopted for large scale poultry waste composting where a windrow/pile is formed having multiple layers of waste materials and bulking agents having a mesh/net cover to avoid predators (Tiquia & Tam, 2002). Windrow composting is a commercially adopted method that may require a concrete floor and a large storage yard as well as machinery to carry out the composting procedure. Anyhow, compost procedure remains the same for both the methods as repeated tunings are required to ensure the thermophilic and aerobic environment for biodegradation of organic matter. Composting can reduce coliform bacteria in offals up to 97% (Bary & Miles, 2001). Das *et al.* (2002) also observed that 99.9% *E. coli* and 100% salmonella were neutralized when hatchery waste was processed under bin composting technique. The biological risks related to mortality can be managed during the composting process as physicochemical characteristics of the original substrate are changed (Bukhari *et al.,* 2017).

Massive broiler production and wet poultry market are responsible for the production of a large amount of poultry waste (dead birds, offal, and hatchery waste) creating permanent biosafety and biosecurity threats to the animal as well as human life. For disposal of these wastes, different strategies are used all over the world, however, in Pakistan, so far, no work has been done on composting. Therefore, the present study has been conducted to evaluate the Physico-chemical and microbiological characteristics of 4 different poultry wastes in two composting systems.

MATERIALS AND METHODS

The present study was conducted at the Compost unit of the University of Veterinary and Animal Sciences (UVAS), Ravi Campus, Pattoki to evaluate physical, chemical, and microbiological analysis of the different types of poultry wastes processed through bin and windrow composting systems. A 2 × 4 factorial arrangement of treatments was applied under Completely Randomized Design. Treatments consisted of 2 composting systems (bin and windrow) and 4 compost types (dead birds, offal, hatchery waste, and a mixture of all). For this purpose, 12 bins were filled with dead birds, hatchery waste, offal, and mixture (visceral organs and poultry feathers) and were replicated 3 times. Before composting, the proximate and mineral profiles of different types of poultry waste were evaluated (Table 1, 2). Compost bins/windrows were filled by following the internationally accepted standard method of bin filling (Ritz & Worley, 2005).

Table 1 – Proximate analysis of different poultry waste before composting.

Treatment	Dry Matter	Moisture	Ether Extract	Crude Protein	Ash
		-------------(%)-------------			
Dead Birds	28.89	71.11	6.96	54.98	5.98
Hatchery Waste	54.36	45.64	0.94	19.69	72.47
Offal	44.94	55.06	1.23	44.94	4.13
Mix Material	78.69	21.33	1.20	25.98	31.87

Table 2 – Mineral count of different types of poultry waste before composting.

Treatment	N	K	P	Ca
	---------- (g kg-1) ----------			
Dead Birds	24.73^{a}±4.36	10.56^{a}± 0.69	31.85^{a}±0.21	65.69^{b}± 2.55
Hatchery Waste	14.73^{d}±1.33	3.04^{d}± 0.14	19.40^{d}±0.40	72.31^{a}± 1.74
Offal	16.46^{c}±2.49	9.71^{b}± 0.16	22.10^{c}±0.88	60.67^{bc}± 1.27
Mix Material	19.16^{b}±2.56	7.54^{c}± 0.09	28.88^{b}±0.74	58.52^{c}± 1.04
p-value	0.0003	<.0001	<.0001	0.0062

$^{a-d}$ Superscripts on different means within column differ significantly ($p\leq0.05$); N: Nitrogen, K: Potassium, P: Phosphorus, Ca: Calcium

The dimension of each bin was 6L × 7W × 5H feet. Dead birds, bedding material, hatchery waste, and offal were collected from Hamdard poultry farm (Pvt) Ltd. and their hatchery, while, offal was obtained from the local poultry market of Okara, Pakistan. Twelve windrow piles, each having dimensions of 6L × 6W × 4H feet on the concrete floor were arranged for windrow composting. A typical compost recipe was followed by mixing 1:10 part by weight of straw as a bulking agent, 1 part by weight of poultry waste, 2 parts by weight of poultry litter, and water 0 to 1/2 part by weight in case of too dry conditions. The mixture provided 55% moisture content and 20:1 to 25:1 C: N ratio, the necessary conditions for successful composting (Figure 1, 2). In the 1st step, the primary bin/windrow was loaded by placing 12 inches layer of used litter on the floor followed by a thin layer of bulking agent, such as wheat straw. In the 2nd step, for each waste material, a single layer of waste material was added six inches aside from the periphery walls of the bin/window to avoid the direct exposure to air and maintain anaerobic conditions. Next, 6 inches thick layer of used litter was added to complete the first layer. After that, subsequent layers of waste materials, bulking agents, and litter was added up to the height of 5 feet. In the final step, 12 inches layer of litter was placed to complete the compost recipe (Ritz & Worley, 2005).

Figure 1 – Bin composting.

Figure 2 – Windrow composting.

Physical Analysis

Soon after setting up the compost bin/windrow, microbial activity started and the temperature began to rise to (161°F). Long probe RevoTemp analog thermometer and long probe digital moisture meters were used to monitor temperature and moisture from each replicate thrice a day, respectively. Whereas, pH was measured using water multi-parameter tester (EUTECH Instruments) by preparing 1: 10 w/v compost water extract (Koberstein, 2002). The first heating cycle or thermophilic phase was completed when the temperature of each poultry waste bin/windrow dropped to 120-130°F. At this stage, all the waste materials were shifted from the primary bin into the secondary bin and all windrow piles were turned for aeration. Again, the temperature started to rise until it reached up to 150-155ºF. The end of the second heating cycle or mesophilic phase was marked by a decline in temperature (115-125ºF) during the 29-30th day in different poultry wastes. At this stage, the compost materials were moved and turned for aeration until completion of the final maturation phase. The maturation phase was completed when the temperature of the compost materials fell to surroundings or room temperature (90-100ºF). The finished product had a black brownish appearance with undetectable, non-pleasant odor and fly menace.

Chemical Analysis

Before the start of the composting process, and at the end of the maturation phase, compost samples (250 g) were collected from different locations and stored in re-closeable airtight sterile Lab Guard Polyethylene (LDPE/LLDPE Blend) Biohazard Specimen Bags. The material was then ground and analyzed for dry matter content, crude protein, ether extract, metabolizable energy, and ash content in the Nutrition Laboratory, UVAS, Ravi Campus, Pattoki. The dry matter contents were obtained by the oven-drying method, crude protein by Kjeldahl method, ether extract by Soxhlet apparatus using anhydrous diethyl ether, crude fiber contents were obtained by using 12.5% sulphuric acid and 12.5% sodium hydroxide solutions, total nitrogen was determined through the digestion of samples in sulfuric acid and then distillation in Kjeldahl, according to Silva & Queiroz (2004). Metabolizable energy was calculated following the NRC (1994) procedure of estimation. Calcium, phosphorus, and ash content were determined according to the procedures of the AOAC (2005). Amino acid profile was determined using an amino acid analyzer while macro minerals like potassium and micro minerals (Mn, Fe, I, and Zn) were measured using atomic absorption spectrophotometer (Tedesco *et al.,* 1995). Chemical reagents were obtained from Vision Scientific Traders, Lahore. Composting processes were carried under strict biosecurity measurements according to the procedure followed by USDA-NRCS.

Microbiological Analysis

The total viable count for *E. coli* was performed by following the method adopted by Cunningham *et al.* (2011). Salmonella and Mycoplasma count were carried out by using the method of Cappuccino & Sherma (2007), while HA/HI was performed to determine the viral load of NDV (NRC, 1994).

Statistical Analysis

The data were analyzed through factorial ANOVA using PROC GLM in SAS software (SAS Institute Inc., version 9.1.3., 2002-03). Significant treatment means were compared through Duncan's Multiple Range (DMR) test (Duncan, 1955) assuming the following mathematical model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha \times \beta)_{ij} + \varepsilon_{ijk}$$

Where,

Y_{ij} = Observation of dependent variable recorded on i^{th} and j^{th} treatment

μ = Population mean

α_i = Effect of i^{th} composting system (i = 1, 2)

β_j = Effect of j^{th} compost type (j = 1, 2, 3, 4)

$(\alpha \times \beta)_{ij}$ = Interaction effect between i^{th} and j^{th} treatment

ε_{ijk} = Residual effect associated k^{th} observation on i^{th} and j^{th} treatment NID ~ 0, σ^2

RESULTS AND DISCUSSION

Temperature

During the composting process, the temperature is a very crucial factor because the microbial activities are greatly affected by the fluctuation of temperature (Tiquia & Tam, 2002). During the primary phase, the highest temperature was recorded in dead birds composting in both systems, whereas, hatchery waste showed minimum temperature. Similar trends were observed during the secondary and curing phase (Figure 3, 4). Significantly higher ($p \leq 0.05$) temperature during the primary phase in dead bird waste might be because whole dead birds carry more decomposing bacteria in their proventriculus and intestine, responsible for rapid decomposition of organs that caused an abrupt rise in temperature. Raza (2016) also reported similar findings in dead birds composting that the biological activities of aerobic microbes caused a rise in temperature to 155-160°F within a couple of days. Hassen *et al.* (2001) found that the temperature of the compost decreases as the bacterial count decreases in the compost material. These findings advocate our results that as the composting process preceded, due to microbial activity and emission of gases, size of compost material decreased and oxygen supply shortened which lowered the bacterial degradation process thus lowering temperature toward the end of each phase because the appropriate amount of oxygen supply is necessary to carry on the aerobic composting (Ghao *et al.,* 2010). Temperature beyond 131ºF is enough to neutralize most of the pathogenic microorganisms (Joshua *et al.,* 1998; Kube, 2002). Similarly, parasites, fecal, and plant pathogens within compost are destroyed when its temperature reaches above 131ºF. The type and texture of waste material also affect the temperature and ultimately speed of the composting process (Bukhari, 2017). Furthermore, bin composting proved to be better than the windrow compost system as the highest temperature (161°F) was recorded among dead birds in the bin composting while the highest temperature during windrow composting was 155°F. A significantly higher temperature during bin composting might be due to the closed configuration of bin compost system that ensured exothermic biological activities of aerobic bacteria through less moisture and temperature loss and better decomposing environment to microbes than in windrow compost system (Raza, 2016).

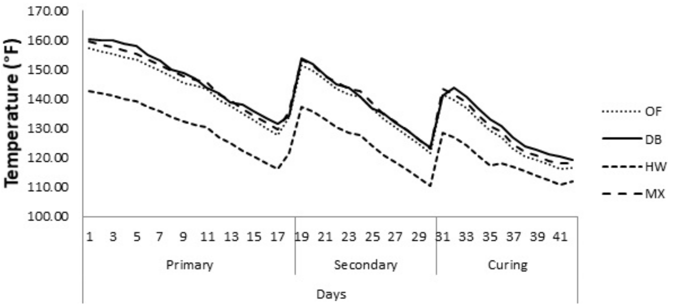

Figure 3 – Temperature variations during different phases of bin composting in different poultry wastes; OF = offal; DB = dead birds; HW = hatchery waste; MX = mixture of all.

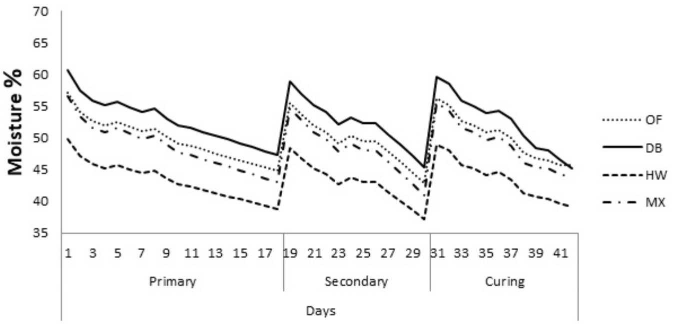

Figure 4 – Moisture variations during different phases of bin composting in different poultry wastes; OF = offal; DB = dead birds; HW = hatchery waste; MX = mixture of all.

Moisture

In the present study, maximum and minimum moisture percentage was recorded in dead birds (66%) and hatchery waste (45%), respectively (Figure 5, 6). Desired moisture is around 50% during the composting process (Hachicha *et al.,* 2006) to maintain the thermophilic conditions. High moisture (65-70%) is not recommended (Nahm, 2005) as it excludes oxygen from the tiny pores of the compost pile and lowers its aerobic activity. High Temp and optimal humidity are pivotal for the composting process (Nahm, 2005). Moreover, Looper (2002) also quoted similar findings that moisture above 60% produces odor and stops temperature to rise. Hatchery waste showed the lowest moisture level that decreases the rate of degradation by lowering microbial activity (Golabi *et al.*, 2003).

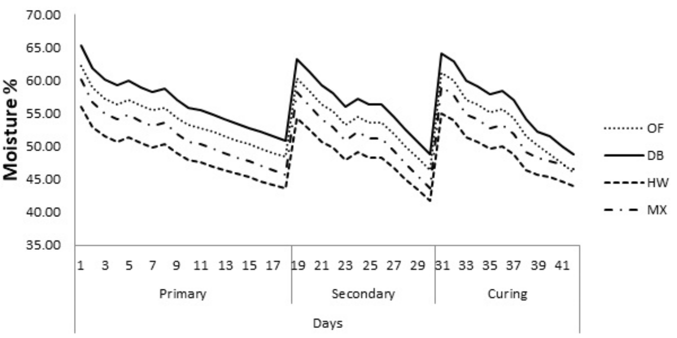

Figure 5 – Moisture variations during different phases of windrow composting in different poultry wastes; OF = offal; DB = dead birds; HW = hatchery waste; MX = mixture of all.

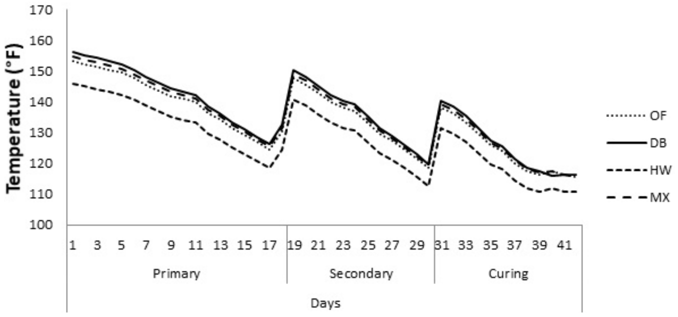

Figure 6 – Temperature variations during different phases of windrow composting in different poultry wastes; OF = offal; DB = dead birds; HW = hatchery waste; MX = mixture of all.

pH

The pH values of different types of poultry waste compost remained non-significant ($p > 0.05$) in both composting systems. During the experiment, the pH range was 8.81 to 8.86 from primary to curing phase among different types of poultry waste compost. This might be due to ammonia produced during compost because ammonium hydroxide increases the pH of the compost (Bukhari, 2017). Similarly, other studies reported that the pH range from 7.27 to 8.53 in the finished phase of compost (Kumar *et al.,* 2007). Likewise, Ahmed *et al.* (2012) also observed a slightly alkaline pH of finished poultry waste compost that indicates stabilization of the end product.

Dry Matter

Dry matter contents in different poultry compost types showed significant difference ($p \leq 0.05$) among treatment groups as the highest dry matter was found in hatchery waste compost followed by mixed material and dead bird waste (Table 3). Higher dry matter in finished compost might be due to high moisture loss during maturation or curing phase. Adeley & Kitts (1983) and Muller (1982) reported increased dry matter content in finished compost due to microbial degradation of organic matter responsible for heat generation and subsequently reducing the moisture contents; weight and volume of finished product and increasing dry matter at the end of the composting process (Gajalakshmi, 2008). Bukhari *et al.* (2017) also reported that the dry matter contents increased as the composting process proceeded. A higher percentage of dry matter during bin composting than windrow composting might be due to higher microbial activity leading to higher temperatures causing more moisture loss than in windrow composting.

Crude protein

Significant differences ($p \leq 0.05$) in CP contents of different poultry waste composts were observed

Table 3 – Proximate composition of different poultry waste materials processed under different composting systems.

CS	DM (%)	CP (%)	Ash (%)	EE (%)	ME (kcal/kg)
Bin	86.55^{a}±0.66	13.06±0.91	34.45^{a} ±1.63	5.20^{b}±0.27	1725.50^{a} ±55.21
Windrow	85.56^{b}±0.81	13.05±0.80	31.42^{b} ±0.89	5.67^{a}±0.14	1658.00^{b} ±54.85
WM					
DB	84.91^{b} ±0.56	16.16^{a} ±0.17	37.14^{a} ±1.31	5.09±0.21^{b}	1848.00^{a} ±17.31
HW	89.95^{a} ±0.49	8.88^{d} ±0.26	36.70^{a} ±1.28	4.62±0.25^{c}	1386.33^{d} ±16.82
MX	84.98^{b} ±0.48	12.19^{c} ±0.16	27.75^{c} ±0.40	5.83±0.15^{a}	1729.00^{c} ±18.87
OF	84.36^{b} ±0.29	15.00^{b} ±0.22	30.15^{b} ±0.38	6.21±0.16^{a}	1803.67^{b} ±17.35
p-value					
CS	0.0166	0.9675	0.0001	0.0031	0.0001
WM	0.0001	0.0001	0.0001	0.0001	0.0001
CS × WM	0.0727	0.2060	0.0001	0.0171	0.9377

$^{a-d}$ Superscripts on different means within column differ significantly ($p \leq 0.05$); CS: Compost System, WM: Waste material; DB: Dead birds, HW: Hatchery waste, MX: Mixed Poultry wastes, OF: offal, DM: Dry matter, CP: Crude Protein, EE: Ether extract, ME: Metabolizable energy

among different waste materials (Table 3). The highest CP content was recorded in dead bird's compost, whereas, the lowest was expressed by hatchery waste compost. The duration of hatchery waste compost was maximum among all compost materials resulting in reduced crude protein value as suggested by Bukhari (2017) that crude protein value decreases with an increase in composting duration. The intensity of microbial degradation of organic matter during the composting process may also be the reason for significantly different crude protein values among different poultry wastes (Babatope, 2012). Tiquia *et al.* (2000) and Sivakumar (2006) also confirmed that crude protein percentage decreases with the time elapsed in the process of composting which cements our results as time elapsed by hatchery waste to complete the composting process was the highest in comparison to dead birds, offal and mix material. It is also to be considered that the dead bird's carcass contained more muscles than other materials, that lead to more crude protein contents (Khan, 2019) than other waste material composts. Moreover, no significant effects of bin and windrow composting were observed on a crude protein of finished product.

Ash (%)

The ash content provides important information about the quality of poultry litter. Different types of poultry waste compost demonstrated variations in ash percentage as hatchery waste compost had the highest value of ash contents while mixed material yield the lowest amount of ash percentage during proximate analysis (Table 3). These results may be due to the time taken to compost process and organic mineralization and degradation (Chefetz *et al.,* 1996). Babatope (2012) stated that ash contents are a measure of mineral contents of the waste material. High ash contents may be due to dirt contamination of fluff and wasted unhatched eggs used for composting. Flachowsky & Hennig (1990) reported that the ash contents increased with the time of composting. Hatchery waste compost took a little longer than mixed material that increased the ash contents. Bukhari *et al.,* (2017) also reported that the increase in the ash contents as the process of composting proceeds. Similar results were also documented by Ch'ng *et al.* (2013) that composting reduced the organic matter that ultimately enhanced the ash content in the final product.

Ether extract

Significant differences ($p \leq 0.05$) were observed in ether extract among different poultry waste composts during the composting process (Table 3). Mix material compost showed the highest value of ether extract while hatchery waste compost exhibited the lowest value of ether extract. It has been observed that the quantity of ether extract and the time of composting process are inversely proportional to each other as Sivakumar (2006) also documented that ether extract decreases over time. Findings from this experiment indicated that hatchery waste compost took more time than any other waste material, thus, lowering the quantity of ether extract contents. These results are in agreement with the findings of Tiquia & Tam (2000), who also reported a decrease in ether extract contents as the compost process proceeds.

Bacterial Count

Salmonella and Mycoplasma and Coliform count

Non-significant differences ($p > 0.05$) were observed regarding means of *Salmonella and Mycoplasma* count among different poultry waste composts during the process of composting (Table 4). The current experiment

Table 4 – Microbial Count of dead bird's compost processed under different composting systems.

Compost System	Salmonella	MG	E Coli (log10)	ND
Bin	Negative	Negative	3.36±0.03	Negative
Windrow	Negative	Negative	3.36±0.03	Negative
Waste Material				
DB	Negative	Negative	3.30[c] ±0.02	Negative
HW	Negative	Negative	3.51[a] ±0.01	Negative
MX	Negative	Negative	3.41[b] ±0.02	Negative
OF	Negative	Negative	3.22[d] ±0.01	Negative
p-value				
Compost System	--	--	0. 9526	--
Waste Material	--	--	0. 0001	--
Interaction	--	--	0.9381	--

[a-d] Superscripts on different means within column differ significantly ($p \leq 0.05$);

DB: Dead birds, HW: Hatchery waste, MX: Mixed Poultry waste, OF: offal, MG: Mycoplasma gallicepticum, ND: New Castle

was completed by subjecting the poultry wastes to two heating cycles (thermophilic and mesophilic stage), which might have reduced bacterial count to an undetectable level. It is quite possible heating cycles during the composting process might have effectively destroyed pathogenic organisms as it is reported that the long composting time can effectively eradicate *Salmonella and Mycoplasma* (Bicùdo & Goyal, 2003; Vinodkumar, 2014). Likewise, findings of Bary & Miles (2001) also strengthen our results that no pathogenic bacteria were found in the waste material after the completion of the composting process.

Means of *Coliform* count showed significant differences among different poultry waste composts but the non-significant difference was observed among different composting systems. Hatchery waste compost had significantly the minimum *Coliform* count while offal's compost had the maximum *Coliform* count among all the poultry waste composts. Long duration and temperature above 140°F during composting are reported to kill pathogens and help to control disease outbreaks (Bonhotal *et al.,* 2008). Minimal *Coliform* count in hatchery waste compost might be due to the long composting time or exposure to two heating cycles (Khan, 2018). *Coliforms* can grow in adverse environments characterized by low pH and low temperatures. Likewise, Bicùdo & Goyal (2003) reported that a long composting time can effectively eradicate *Coliform* bacteria. Imbeah (1998), similarly, stated that composting reduces the pathogenic organisms due to the high heat produced during the process of compositing. It is also noted that all microbial flora is inactivated within 24h as the temperature reaches around 50°C during an aerobic thermophilic phase (Bicùdo & Goyal, 2003). Significantly higher microbial load in offal might also be due to the high moisture contents and short time of completion in the composting process as Kim *et al.* (2012) quoted similar results that temperature and moisture contents of material directly affect the microbial count in the end product. According to Gradel *et al.* (2003) and Bukhari (2017), microbial load decreases with the increase in the duration of the composting process. These findings strongly favor our results that hatchery waste took the longest completion time as compared to other waste material composts having a minimum microbial load. These results are confirmed by Martin (1998) who reported that the *E. coli* and Salmonella were not detected in the composting experiment.

New Castle Disease

Newcastle disease (ND) is a highly contagious viral disease caused by a paramyxovirus. Every animal has a defense system called cellular immunity which can be used as a parameter of the immune response. Heam Agglutination and Heam Inhibition (HA/HI) is performed to evaluate titers that can be used as a marker for the immune system. ND titers showed non-significant differences ($p>0.05$) among different treatment groups (Table 4). These negative results indicated that all viruses have been neutralized during the composting process regardless of the composting system and materials. It might also be possible that materials used in the composting process may not have ND infection or exposure to field virus that leads to a minimum load of NDV during HA/HI. High temperatures up to 165F may also have killed ND viruses leading to negative results.

Mineral Count

Nitrogen

The nitrogen contents showed significant differences ($p \leq 0.05$) among different types of poultry waste composts whereas no significant difference was observed among different composting systems during the experiment (Table 5). The maximum value of nitrogen contents was recorded in the dead bird's compost while the lowest nitrogen contents were observed in hatchery waste compost. This may be due to the volatilization of ammonia during the process of composting. These results are in line with the finding of Sivakumar *et al.* (2007) who reported that nitrogen is reduced during the process of composting and confirmed by Lin *et al.* (2013) who found that decrease in nitrogen contents during the process of composting is mainly due to ammonia loss that may lower the contents up to 71% if compost process is slow. Similarly, Bukhari *et al.* (2017) reported that the nitrogen contents decreased as the composting process matured. Moreover, the findings of Valente *et al.* (2014) also strengthen our results that alkaline pH and temperature fluctuations favored N volatilization. These results agree with Kelleher *et al.* (2002) who reported that the low C: N ratio of hatchery residues contributes to losses of hydrogen sulfide and ammonia.

Potassium

During the composting process, significant differences ($p \leq 0.05$) were observed regarding potassium contents among different types of poultry waste composts in different phases while bin composting system showed significantly ($p \leq 0.05$) better effects on potassium contents (Table 5). In the curing phase of compost, the maximum value of potassium contents was recorded in the dead bird's compost while the lowest potassium contents were observed in hatchery waste. The increase of potassium contents in dead birds during the curing phase may be due to the degradation of organic matter and mineralization, as it is reported that the increase of potassium content is due to the loss of organic matter during the process of composting (Chefetz *et al.,* 1996). Bukhari *et al.* (2017) concluded that the potassium contents increase as the composting process reaches its curing phase. Similar results were reported by Sakthivadivu *et al.* (2015) of the increasing trend of potassium contents in the curing phase. Likewise, Kumar *et al.* (2007) observed similar results in dead bird compost that advocate our findings. This increase might be attributed to higher initial total organic matter and agrees with Veras *et al.* (2004) who stated that those waste materials having higher contents of the organic matter showed a higher concentration of potassium because the minerals are electrostatically adsorbed to organic matter. Similarly, higher nitrogen contents in bin composting might be due to less leakage of nitrogen through ammonia emission because of less exposed surface area as compared to windrow piles.

Phosphorus

The phosphorus contents revealed a significant difference ($p \leq 0.05$) among different poultry waste composts and systems (Table 5). The highest value of phosphorus contents was recorded in the dead bird's compost while the lowest value was observed in hatchery waste while waste materials processed through bin composting showed better phosphorus contents as compared to windrow composting system. The decomposing process in dead birds is rapid as compared to hatchery waste which promotes mineralization and breakdown of organic matter to simpler molecules (Khan, 2018). Similarly, higher phosphorus content in dead bird's compost has been reported previously by Bukhari *et al.* (2017) and Kumar *et al.* (2007). Hence, the dead bird's compost showed better microbial activity that leads to P immobilization by microbial cells (Valente *et al.,* 2014).

Table 5 – Mineral count of different types of poultry waste after composting.

CS	N (%)	K (%)	P (%)	Ca (%)
Bin	2.02±0.14	1.31^a ±0.05	0.95^a ±0.02	0.92^a±0.09
Windrow	2.03±0.14	1.12^b ±0.06	0.87^b ±0.01	0.91^b±0.97
WM				
DB	2.54^a ±0.03	1.38^a ±0.04	0.98^a ±0.03	0.60^c ±0.20
HW	1.31^d ±0.02	0.92^c ±0.04	0.84^c ±0.01	1.30^a ±0.16
MX	1.88^c ±0.03	1.17^b ±0.08	0.91^b ±0.02	1.15^b ±0.01
OF	2.37^b ±0.02	1.39^a ±0.02	0.92^b ±0.01	0.61^c ±0.01
P-value				
CS	0.9789	0.0001	0.0001	0.0072
WM	0.0001	0.0001	0.0001	0.0001
CS × WM	0.1065	0.0001	0.9745	0.0165

$^{a-d}$ Superscripts on different means within column differ significantly ($p \leq 0.05$);

CS: Compost system, WM: Waste material, DB: Dead birds, HW: Hatchery waste, MX: Mixed Poultry waste, OF: offal; N: Nitrogen, K: Potassium, P: Phosphorus, Ca: Calcium

Calcium

Significantly ($p \leq 0.05$), the highest calcium contents were observed in hatchery waste compost whereas the lowest calcium contents were observed in mixture compost, however, the non-significant effect of composting systems was observed during the experiment (Table 5). Hatchery waste mostly comprised of un-hatched eggs and eggshells added significantly higher calcium contents among other poultry wastes (Kingori, 2011). The loss of organic matter during the composting process might be the possible reason for the increase in the Ca content in finished compost (Bukhair, 2017). Sakthivadivu *et al.* (2015), likewise, reported an increasing trend in Ca content from the primary to the secondary stage of composting. Kumar *et al.* (2007) also reported a similar progressive increase in total Ca content as composting proceeded.

CONCLUSIONS

Based on the current study, an inference can be drawn that bin and windrow composting systems can be adapted for safe and hygienic disposal of different poultry wastes. However, dead birds compost processed through bin composting system had an ideal proximate composition having minimal pathogenic load with superior amino acid and mineral profile as compared to other poultry waste materials and it can further be used as bio-fertilizer. Moreover, bin composting is a more convenient and environmentally safe disposal option than the systems traditionally used in Pakistan.

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CONFLICT OF INTEREST

No potential conflict of interest was found by the authors.

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