不同銅鋅含量飼糧對生長肥育豬糞便及堆肥中銅鋅含量之影響 [1]

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摘要

本試驗旨在探討於豬隻飼糧添加不同化學型式和不同添加量的銅和鋅，對其糞便中含量與糞便堆肥化後含量之影響。選取體重 30.5 ± 2.5 kg 之 LYD 豬隻 72 頭，逢機分置於 4 種不同銅和鋅含量或化學型式之飼糧處理組，飼養至平均體重 110 kg 結束。A 組豬隻在生長期基礎飼糧中分別添加硫酸鹽型式的銅和鋅，使飼糧中的銅和鋅含量分別為 35 mg/kg 及 120 mg/kg，肥育期則添加相同化學型式的銅及鋅，使飼糧中的銅和鋅含量分別為 35 mg/kg 及 100 mg/kg；B 組及 C 組在生長期與肥育期基礎飼糧中，分別添加硫酸鹽型式與蛋白質螯合型式的銅 6 與 4 mg/kg，及鋅 60 與 50 mg/kg；D 組豬隻則餵飼基礎飼糧。試驗期間採集飼糧，每週收集各豬欄糞便，分析銅、鋅、氮、磷和鉀的含量，每 2 – 3 日收集並記錄各處理組糞便量後儲放，供堆肥製作用。結果顯示，A 組豬隻糞便乾物質銅和鋅的含量皆極顯著地高於 D 組，B、C 兩組間差異無顯著，且生長期和肥育期糞便乾物質銅和鋅的含量皆高於 D 組（P＜0.01）。各組豬隻糞便經堆肥化後，銅的濃度約較堆肥化前提高 1.21 – 1.41 倍，鋅的濃度也提高 1.04 – 1.13 倍。各組豬隻糞便和堆肥銅和鋅的濃度，皆隨著飼糧中銅和鋅添加量的增加而顯著地（P＜0.05）提高，而 A 組堆肥乾物質中銅（125 mg/kg）和鋅（785 mg/kg）的含量明顯高於其他三組，並且超出目前的法令規範。

關鍵詞：堆肥、銅、糞便、生長肥育豬、鋅。

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緒言

為降低銅和鋅對農地的危害（Dozier *et al*., 2003; Muehlenbein *et al*., 2001），我國訂定嚴格的規範標準（肥料種類品目及規格，2010），規定畜禽糞製作的堆肥產品中銅和鋅的含量。銅和鋅是豬隻必需的營養分（NRC, 1998），如果為符合堆肥規範而影響豬隻經濟性狀，則兩者必須適度取得平衡，以達到雙贏目標。肥料種類品目及規格（2010）規定，畜禽糞堆肥（品目 5﹣09）的銅及鋅含量必須在 100 ppm 及 500 ppm 以下。NRC（1998）對豬隻銅及鋅的建議營養需要量分別為：體重 3﹣10 kg 時 6 及 100 ppm；10﹣20 kg 為 5 及 80 ppm；20﹣50 kg 為 4 及 60 ppm；50-80 kg 為 3.5 及 50 ppm；80﹣120 kg 為 3 及 50 ppm；我國國家標準（2000）規定，生長期和肥育期豬隻飼糧中銅和鋅的限量必須在 35 和 120 ppm 及 35 和 100 ppm 以下。豬隻對銅（Coffey *et al*., 1994；Apgar *et al*., 1995）和鋅（Buff *et al*., 2005）的吸收率僅約 10﹣30%。Veum *et al*. (2004) 指出，以蛋白質螯合型式的銅 50 ppm 餵飼保育豬，可較添加硫酸鹽型式的銅 250 ppm 組，提高銅的吸收及蓄積，並減少 23% 之銅排泄量。Buff *et al*.（2005）也證實，在飼糧中分別添加氧化鋅型式的鋅 2,000 ppm 與多醣螯合型式的鋅（Zn-polysaccharide）450 ppm，餵飼 36－56 日齡的保育豬，其鋅的排泄量添加多醣螯合型式較添加氧化鋅型式組降低 76%。綜合上述試驗結果，有機型式銅和鋅的生物可利用率可能較無機型式者為高。為改善豬隻排泄物重金屬污染問題，本研究利用生長肥育豬飼糧添加不同化學型式和不同含量的銅和鋅，探討對豬隻糞便排泄物和堆肥的銅和鋅含量之影響。

材料與方法

Ⅰ. 試驗動物及處理

(i) 本研究之動物試驗於 2008 年 5﹣8 月間進行，選取體重 30.5 ± 2.5 kg 的生長豬 72 頭，閹公豬和肉女豬各 36 頭，逢機分置在 A、B、C 和 D 等 4 種不同化學型式和不同銅和鋅添加量之飼糧處理組，飼養到豬隻平均體重 110 kg 結束。

(ii) A 組豬隻餵飼在生長期與肥育期的基礎飼糧中，參照國家標準（2000）的最高限量，添加硫酸鹽型式的銅和鋅，使飼糧中的銅含量皆為 35 mg/kg，鋅含量則分別為 120 mg/kg 及 100 mg/kg；B 組及 C 組豬隻飼糧參照 NRC（1998）推薦之營養需要量，分別在生長期與肥育期的基礎飼糧中添加硫酸鹽型式或蛋白質螯合型式的銅 6 與 4 mg/kg 及鋅 60 與 50 mg/kg；D 組則餵飼基礎飼糧。

(iii) 豬隻生長期（體重 30﹣70 kg）與肥育期（體重 70﹣110 kg）的基礎飼糧（D 組飼糧），皆以玉米－大豆粕為主要原料，成分如表 1 所示。

(iv) 每處理 6 欄，每欄（3.1 m × 1.3 m）飼養同性別豬隻 3 頭，試驗期間飼糧與飲用水均採任食。試驗在畜產試驗所產業組豬舍進行，動物使用、飼養及實驗內容，通過畜產試驗所「實驗動物審查小組」審查。

Ⅱ. 飼糧、飲用水及糞便收集

（i）飼糧配製

在豬隻生長期和肥育期分別調製 4 次和 6 次飼糧，各處理組每次調製 500 kg，飼糧調製後採樣備檢。

表 1. 試驗飼糧銅、鋅、氮、磷及鉀分析值 [1,2]

Table 1. The analyzed value of copper, zinc, nitrogen, phosphorus and potassium in experimental diets

Items	Group A	Group B	Group C	Group D	SE
Grower（n＝4）					
Cu, mg/kg	38.8[a]	28.9[ab]	25.6[b]	13.2[b]	4.1
Zn, mg/kg	110.5[a]	74.4[b]	74.3[b]	27.8[c]	6.3
N, %	2.74	2.73	2.75	2.73	0.06
P, %	0.67	0.65	0.70	0.67	0.05
K, %	0.92	0.85	0.72	0.79	0.13
Finisher（n＝6）					
Cu, mg/kg	39.4[a]	26.1[ab]	25.4[b]	14.1[b]	3.5
Zn, mg/kg	107.9[a]	63.5[b]	67.7[b]	28.9[c]	7.4
N, %	2.42	2.40	2.40	2.41	0.05
P, %	0.64	0.59	0.61	0.64	0.04
K, %	0.71	0.58	0.76	0.58	0.15

[1] Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[2] Dry matter basis.

[a, b, c] Within the same row without the same superscript are significantly different (P＜0.05).

（ii）糞便及飲用水

1. 試驗期間在每一豬欄的生鐵板上方鋪設 0.55 m × 1.3 m 的鋁製花板，在水泥地面和生鐵板之間預留 0.05 m × 1.3 m 孔隙，以便收集糞便後清洗豬欄。每週一、週三和週五上午各以人工收集糞便一次，依照處理組分別堆置於堆肥舍。
2. 試驗開始時，及試驗期間（試驗第 7 週因從生長期轉為肥育期，未採樣）每週一下午採集各欄的糞便樣品一次，秤重後置於 55 ± 1℃的熱風循環烘箱（CHANNEL DV-1202H）烘乾 2－3 天，記錄烘乾後重量，隨後將個別樣品粉碎裝入#8 封口袋，於常溫下儲存備檢。
3. 每週收集糞便樣品同時採集各欄豬隻的飲用水。

Ⅲ. 堆肥製作及腐熟度判定

（i）各組收集之糞便分別以粗糠和飲用水，參考林（1998）調整碳氮比及水分後（表 2），進行 56 天（2008/9/11－2008/11/6）的堆積式堆肥化處理，並於堆肥化處理第 20 天及第 35 天進行翻堆及調整水分。

表 2. 堆肥化前成分調整

Table 2. The adjustment of pig feces-on-litter composition before composting

Items	Group A	Group B	Group C	Group D	Rice hull
Before adjustment					
Fecal weight, kg	152.40	114.80	113.50	139.85	—
Moisture, %	41.67	22.31	19.23	19.87	8.35
Added					
Rice hull, kg	23.65	23.25	23.30	23.30	—
Water, kg	140.00	155.20	168.45	172.50	—
After adjustment					
Litter weight, kg	316.05	293.25	305.25	335.65	—
Dry matter weight[3], kg	110.57	110.50	113.02	133.41	—
Moisture, %	65.01	62.32	62.97	60.25	—

[1] Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[3] Estimated value, Dry matter weight= fecal dry matter + rice hull dry matter.

（ii） 醱酵溫度測定：在各處理組堆肥的中心點配置溫度計（Thermometer, Chuan instrument Co., Tainan, Taiwan），每日上午 08:30 – 09:00 以人工記錄溫度。

（iii）採集各組堆肥化之前及完成堆肥化的樣品，秤重後置於 55 ± 1℃的熱風循環烘箱（CHANNEL DV-1202H）2 – 3 天，紀錄烘乾後重量，隨後將個別樣品粉碎裝入#10 封口袋，於常溫下儲存備檢。

（iv）相對發芽率（relative seed germination, RSG）測定：參考 Tiquia *et al.*（1996）及 Tiquia（2010）之方法，以結球甘藍（Chinese cabbage）及苜蓿（alfalfa）種籽，測定各組堆肥萃取液和對照組的 RSG，測定方法如下：

1. 取烘乾的堆肥樣品磨成粉末狀。每樣品 4 重複，取 5 g 的樣品於小燒杯中，加入 50 mL 的蒸餾水（水溫約 75 – 80℃），攪拌均勻後，靜置 3 小時。
2. 培養皿平舖 90 nm 孔徑的濾紙，放入 100 顆種子。
3. 取各組過濾後濾液 8 mL 於培養皿中，對照組加入 8 mL 蒸餾水，於 25℃恒溫箱中放置 5 天，計算發芽種籽數。
4. 計算公式：RSG（%）＝處理組平均發芽數/對照值平均發芽數 ×100%。

IV. 分析項目及方法

（i） 飼糧、糞便及堆肥：分析銅、鋅、氮、磷及鉀的濃度。

（ii） 飲用水：分析銅及鋅的濃度。

（iii） 氮和磷分析：依照 AOAC（1990）所述測定。

（iv） 銅、鋅及鉀分析：依照 AOAC（1990）所述，烘乾的飼糧、糞便及堆肥樣品，經灰化（灰化爐，NEYTECH-2-525）後，以原子吸收光譜儀（Atomic absorption spectrophotometer Z8100, Hitachi）

測定。

V. 統計分析

利用 SAS 統計分析套裝軟體的一般線性模式程序（General linear model procedure）進行變方分析（SAS, 2002）。飼糧和糞便分別以每次調製和欄為試驗單位，以 least squares mean 估計各處理組的最小均方平均值及標準機差，再以特奇公正顯著差異法（Tukey's honest significant difference, HSD），比較各處理組間的差異顯著性。

結果與討論

本試驗豬隻飼糧、糞便及堆肥的銅、鋅、鉀、氮和磷含量，皆以乾基表示。飼糧中銅、鋅、鉀、氮和磷的含量分析結果，示於表 1。各組飼糧中鉀、氮和磷的含量均無顯著差異，而銅和鋅的含量皆隨著添加量的增加而提高。試驗期間共採集飲用水 13 次（資料未列於表中），分析結果顯示，鋅的濃度為 0.38 ± 0.31 mg/L，銅則皆未檢出（＜0. 01 mg/L）。

試驗開始時和試驗期間每週一下午採集各欄的糞便樣品一次，其中試驗第 7 週因豬隻從生長期轉為餵飼肥育期飼糧，為免混淆而未採樣分析。各處理組豬隻糞便中銅、鋅、氮、磷及鉀的含量分析結果，示於表 3。豬隻生長期糞便中的磷和鉀濃度，以及肥育期的磷濃度，各組間皆無顯著差異。不論生長期或肥育期飼糧，各組的氮、磷和鉀含量均相近（表 1），惟 B 組豬隻在生長期和試驗全期糞便中氮的濃度皆較 A 組為高（$P<0.05$），C 組豬隻在生長期和試驗全期糞便中氮和鉀的濃度亦顯著地高於 A 組，此與 Dove（1995）證實，飼糧銅含量和鉀（$P=0.07$）與氮（$P<0.01$）的蓄積呈正相關之結果相左；蘇等（2012）指出，本試驗 A 組豬隻的平均飼料採食量極顯著地較 B 組和 C 組為多，是否因為飼料採食量較多而影響鉀和氮的消化吸收，致糞便中氮和鉀的濃度提高，有待後續探討。不論在生長期或肥育期，A 組豬隻糞便中銅和鋅的濃度極顯著地較其他三組為高，而 B 組和 C 組豬隻糞便中銅和鋅的平均濃度相近，且較 D 組為高（$P<0.01$）。本試驗 B 組和 C 組飼糧分別添加硫酸鹽或蛋白質螯合型式的銅和鋅，其添加量分別參照 NRC（1998）的銅和鋅需要量，而不論生長期或肥育期，B 組和 C 組豬隻糞便銅和鋅的濃度皆相近。此與其他報告（Buff *et al*., 2005; Veum *et al*., 2004）指出，有機型式的銅和鋅其消化吸收率較無機型式者為佳之結果似有相左，推測係由於 Buff *et al.*（2005）和 Veum *et al.*（2004）皆以含較高量的無機銅和鋅飼糧與含較低量的有機銅和鋅相比較。例如 Buff *et al.*（2005）在飼糧中添加氧化鋅型式的鋅 2,000 ppm 與多醣類螯合型式的鋅（Zn-polysaccharide）450 ppm 相比較，而 Veum *et al.*（2004）則在飼糧中添加硫酸鹽型式的銅 250 ppm 與添加蛋白質螯合型式的銅 0、50 及 100 ppm 相比較。因上述報告無機銅和鋅的供應量皆明顯較有機銅和鋅為高，致使消化吸收率降低使然。各組生長期糞便乾物質銅和鋅的含量分別約為飼糧乾物質銅和鋅含量的 3.0－3.8 倍和 7.6－15.3 倍，肥育期則為 1.6－2.2 倍和 4.5－10.1 倍，而糞便銅及鋅的含量隨著飼糧中銅及鋅添加量的增加而顯著地（$P<0.05$）提高。

表 3. 飼糧添加不同化學型式及添加量的銅和鋅對豬隻糞便中銅和鋅濃度之影響 [1,2]

Table 3. Effect of adding different chemical forms and levels of copper and zinc to diets on fecal copper and zinc concentrations of growing-finisher pigs[1,2]

Items	Group A	Group B	Group C	Group D	SE
Grower（n＝6）					
Cu, mg/kg	149^{x}	93^{y}	78^{y}	48^{z}	5
Zn mg/kg	837^{x}	684^{y}	612^{y}	427^{z}	23
N, %	1.11^{b}	1.48^{a}	1.43^{a}	1.21^{b}	0.06
P, %	2.33	2.45	2.39	2.43	0.04
K, %	2.83	3.03	3.01	3.05	0.06
Finisher（n＝6）					
Cu, mg/kg	86^{x}	45^{y}	39^{y}	26^{z}	3
Zn, mg/kg	595^{x}	345^{y}	303^{y}	294^{y}	24
N, %	1.21	1.20	1.11	1.14	0.09
P, %	1.96	2.14	1.97	1.91	0.07
K, %	2.77^{b}	2.86^{ab}	3.02^{a}	2.83^{ab}	0.05
Overall					
Cu, mg/kg	121^{x}	71^{xy}	61^{xy}	39^{y}	4
Zn, mg/kg	729^{x}	533^{xy}	475^{xy}	368^{y}	25
N, %	1.16^{b}	1.35^{a}	1.29^{ab}	1.19^{ab}	0.05
P, %	2.17	2.31	2.21	2.20	0.05
K, %	2.81^{b}	2.95^{ab}	3.01^{a}	2.95^{ab}	0.04

[1] Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[2] Dry matter basis.

[a, b, c] Within the same date without the same superscript are significantly different (P＜0.05).

[x, y, z] Means within the same row without the same superscript are highly significantly different (P＜0.01).

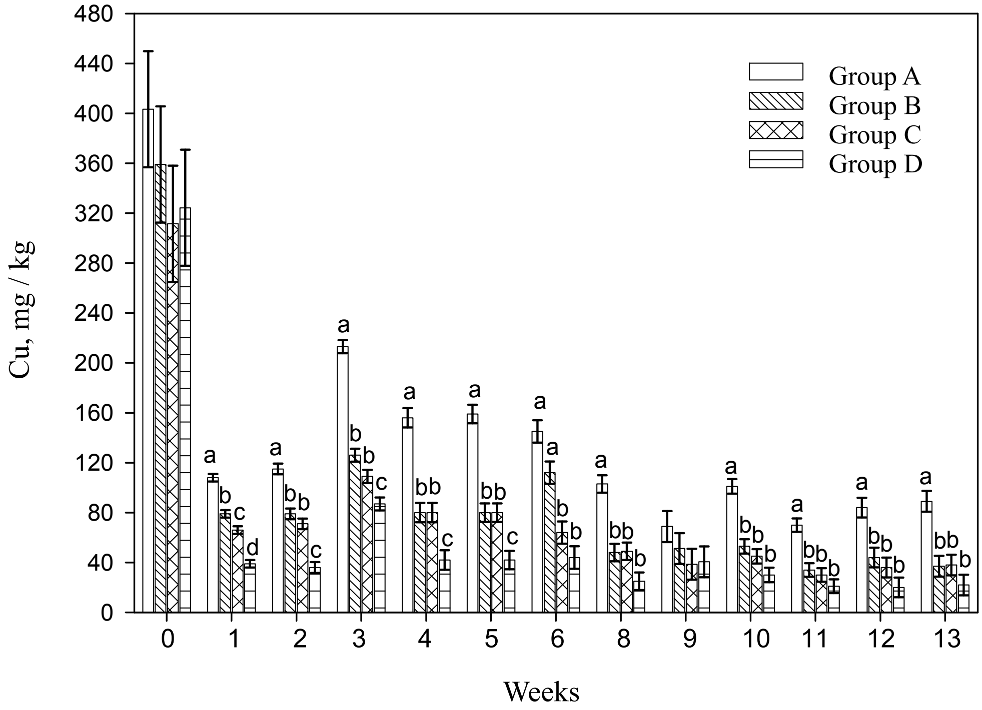

圖 1. 飼糧添加不同化學型式及添加量的銅對豬糞（乾基）中銅濃度之影響。

Fig. 1. Effect of adding different chemical forms and levels of copper to diets on fecal copper concentration (dry matter basis) of growing-finishing pigs[1].

Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[a, b, c] Data were LSM ± SE and within the same date without the same superscript are significantly different (P＜0.05).

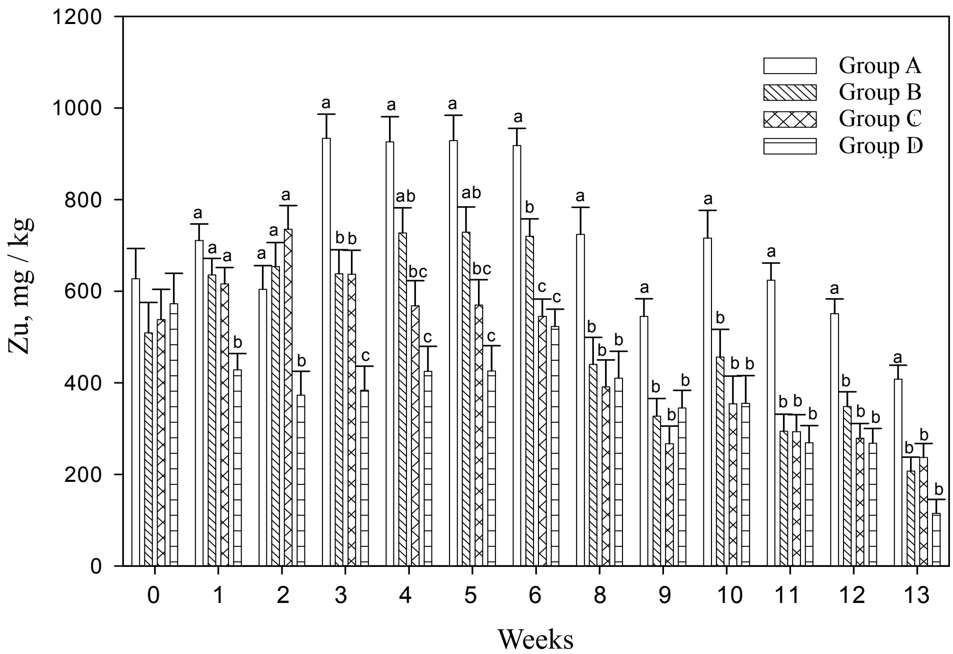

圖 2. 飼糧添加不同化學型式及添加量的鋅對豬糞（乾基）中鋅濃度之影響。

Fig. 2. Effect of adding different chemical forms and levels of zinc to diets on fecal zinc concentration (dry matter basis) of growing-finishing pigs.

Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[a, b, c] Data were LSM ± SE and within the same date without the same superscript are significantly different (P＜0.05).

試驗期間各週豬隻銅和鋅的排泄情形，示於圖 1 及圖 2。由於試驗前提供參試豬隻相同的飼糧，其礦物質預混料含有 7 mg/kg 的銅和 70 mg/kg 的鋅（皆屬硫酸鹽型式），且另添加 0.4 kg/ton 的硫酸銅（$CuSO_4$· $5H_2O$），經計算飼糧銅含量在 110 mg/kg 以上。因此，在試驗開始時（第 0 週）各組豬隻糞便中銅的濃度皆高達 300 mg/kg 以上（圖 1）。除了在試驗第 9 週時各組糞便的銅濃度相近外，皆以 A 組豬隻糞便的銅濃度明顯高（P＜0.05）於其他三組，而 B 組和 C 組豬隻生長期糞便的銅濃度顯著高於 D 組，但肥育期時 B、C、D 組糞便的銅濃度差異皆無顯著。

在鋅的排泄方面，試驗開始時（第 0 週）各組豬隻糞便中鋅的濃度皆相近，介於 509－627 mg/kg 間（圖 2）。B 組和 C 組豬隻生長期飼糧的鋅含量雖然比 A 組顯著為低（表 1），但 A、B、C 三組在試驗第 1 週和第 2 週豬隻糞便鋅的濃度差異皆無顯著，而 B 組和 C 組肥育期飼糧的鋅含量顯著較 D 組為高，但是在肥育期 B、C、D 三組的豬隻各週糞便的鋅濃度差異皆無顯著。NRC（1998）指出，豬隻

對硫酸銅（$CuSO_4$‧ $5H_2O$）、硫酸鋅（$ZnSO_4$‧ $7H_2O$）和氧化鋅（ZnO）的生物可利用率（bioavailability）分別為 100%、100%及 50-80%；Veum *et al.* （2004）指出，以蛋白質螯合型式的銅 50 ppm 餵飼保育豬，可較添加硫酸型式的銅 250 ppm 組提高銅的吸收及蓄積，並減少 23% 之銅排泄量。Buff *et al.*（2005）也證實，在飼糧中分別添加氧化鋅型式的鋅 2,000 ppm 與多醣螯合鋅型式的鋅（Zn-polysaccharide）450 ppm，餵飼 36－56 日齡的保育豬，其鋅的排泄量餵飼添加多醣螯合鋅型式較添加氧化鋅型式組降低 76%。顯示，雖然豬隻對硫酸型式的銅和鋅之生物可利用率可達到 100%（NRC, 1998），但攝取量超出需要量時，亦無法完全吸收利用。

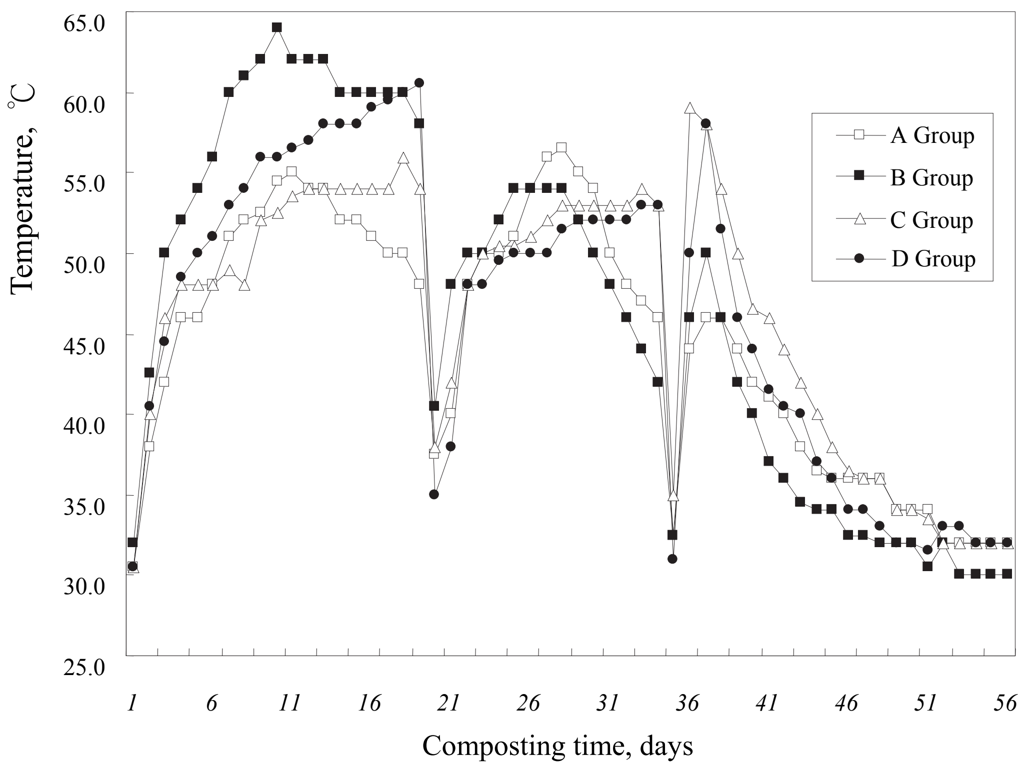

圖 3. 堆肥化期間溫度變化。

Fig. 3. The temperature change during composting period.

Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

收集各組試驗期間之糞便依照組別儲放於堆肥舍，豬隻生長試驗結束後參考林（1998），加入適量的豬隻飲用水及粗糠，調整水分及碳氮比，進行堆肥化前之成分調整（表 2）。堆肥化採取堆積式醱酵，分別於堆肥化第 20 天及第 35 天共進行 2 次翻堆，期間各組堆肥化的溫度變化示於圖 3。本試驗以醱酵溫度作為初步判定堆肥腐熟度之指標，堆肥化期間以 B 組最高醱酵溫度達 64℃最高，A 組最高醱酵溫度僅 56.5℃最低，而在第 45–56 天醱酵溫度趨於一致，故在第 56 天結束堆肥化處理。

表 4. 飼糧添加不同化學型式及添加量的銅和鋅對豬糞堆肥化後相對發芽率之影響 [1]

Table 4. Effect of adding different chemical forms and levels of copper and zinc to diets on RSG of after litter composting[1]

Items	Control	Group A	Group B	Group C	Group D	SE
Chinese cabbage						
No. of germination, plant	94.8	19.0	17.8	15.5	18.5	3.1
RSG[4], %	—	20.1	18.7	16.4	19.5	3.3
Alfalfa						
No. of germination, plant	93.0	91.3	91.8	92.5	91.8	1.3
RSG, %	—	98.1	98.7	99.5	98.7	1.4

[1] Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

[4] RSG: number of seeds germinated in litter extract/number of seeds germinated in control × 100.

豬糞堆肥化期間的腐熟過程可以將對植物有害物質（phytotoxic metals）之性質趨於穩定（Tiquia *et al*., 1997; Tiquia, 2010），並可藉由發芽率測定來評估堆肥的腐熟度（Ros *et al*., 2006; Miaomiao *et al*., 2009; Tiquia, 2010）。本試驗經初步以醱酵溫度判斷堆肥腐熟度後，選用結球甘藍及苜蓿種籽進行相對發芽率（RSG）測定，結果示於表 4。結球甘藍及苜蓿的 RSG 各組間皆相近，結球甘藍僅 16–20%，苜蓿的 RSG 皆達 98%以上。Kim *et al.*（2008）選用結球甘藍及大白菜進行堆肥腐熟度評估，結果各試驗組結球甘藍的 RSG 僅 0–40.0%，大白菜卻高達 104.0–164.4%，與本試驗結果兩種植物種籽的 RSG 差異甚大之結果相似；Kim *et al.*（2008）認為此與結球甘藍及大白菜種籽對堆肥中的銅及鋅的耐受度有關。採集經成分調整之堆肥化前和完成堆肥化的樣品，分析堆肥化前後成分變化情形，結果列於表 5。堆肥化後銅的濃度約較堆肥化前提高 1.21–1.41 倍，鋅的濃度也提高 1.04–1.13 倍。Hsu and Lo（2001）指出，豬糞在堆肥化過程中，隨著豬糞中有機物被分解，堆肥銅和鋅濃度較堆肥化前提高 2.7 倍；Tiquia（2010）的研究，堆肥化後銅（530–660 μg/g）和鋅（650–930 μg/g）的濃度分別約較堆肥化前（銅 420-550 μg/g 及鋅 530–660 μg/g）提高 1.20–1.26 倍和 1.23–1.41 倍。此與堆肥化期間有機質和有機碳（Parkinson *et al*., 2004; Tiquia, 2010）被分解，以及氮被分解產生 NH_3、NO_3-N 和 NH_4-N 等而逸散（Bernal *et al*., 2009），致使礦物質元素的濃度被濃縮而相對提高（Miaomiao *et al*., 2009）有關。

表 5. 豬糞堆肥化前後成分之變化 [1,2]

Table 5. The compositions change during composting process of pig feces-on-litter[1,2]

Items	Group A	Group B	Group C	Group D
Before composting				
Moisture, %	60.66	64.65	65.75	64.95
Ash, %	28.17	23.77	23.57	24.45
Cu, mg/kg	103	54	46	34
Zn, mg/kg	721	439	390	278
N, %	3.02	2.80	2.92	2.89
P, %	2.54	2.74	2.38	2.80
K, %	2.42	2.69	2.63	2.23
After composting				
Moisture, %	40.96	38.71	41.54	41.96
Ash, %	35.48	33.15	31.49	32.36
Cu, mg/kg	125	70	57	48
Zn, mg/kg	785	470	406	315
N, %	2.21	2.33	2.27	2.25
P, %	3.48	3.59	3.49	3.49
K, %	2.97	3.10	2.91	2.67

1 Group A was fed the basal diet with copper at 35 mg/kg and zinc at 120 mg/kg and 100 mg/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$, respectively. Groups B and C were fed the basal diet with two chemical forms of copper and zinc i.e., 6 mg Cu/kg and 60 mg Zn/kg and 4 mg Cu/kg and 50 mg Zn/kg in grower and finisher period by adding $CuSO_4$ and $ZnSO_4$ or Cu-proteinate or Zn-proteinate, respectively. No addition of Cu and Zn in experimental period of group D.

2 Dry matter basis, except content of moisture.

經堆肥化處理後，A 組堆肥的銅（125 mg/kg）和鋅（785 mg/kg）的濃度均明顯高於其他三組，而各組間氮（2.21 – 2.33%）、磷（3.48 – 3.59%，換算 P_2O_5 為 7.97 – 8.22%）及鉀（2.67 – 3.10%，換算 K_2O 為 3.22 – 3.74%）的濃度相近。肥料種類品目及規格（2010）規定，畜禽糞堆肥（品目 5 – 09）必須以禽畜糞為主原料（50%以上），銅及鋅含量限制在 100 ppm 及 500 ppm 以下，全氮 1.0%以上、4.0%以下，全磷酐（P_2O_5）1.0%以上、6.0%以下，全氧化鉀（K_2O）0.5%以上、5.0%以下。本試驗餵飼 A 組豬隻的飼糧係依照國家標準（2000）銅和鋅最高限量添加，惟製成之堆肥中銅、鋅和磷的濃度，均高於畜禽糞堆肥（品目 5 – 09）之規範；A 組豬隻糞便在堆肥化前雖已添加 23.65 kg 的粗糠，堆肥化處理後其銅、鋅及磷含量仍然高於畜禽糞堆肥（品目 5 – 09）之規範，而氮（2.21%）和鉀（2.77%）皆尚有調降空間，如果再額外增加調整材用量降低銅、鋅及磷的濃度，可否符合畜禽糞堆肥（品目 5 – 09）之規範，有待後續評估。此外，B、C 和 D 等三組堆肥中的銅和鋅含量，均符合畜禽糞堆肥（品目 5 – 09）之規範。

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Effects of different levels of copper and zinc in growing-finishing pigs diet on the copper and zinc concentrations in feces and compost[(1)]

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Abstract

The purpose of this study was to investigate the effect of dietary supplementation with different chemical forms and levels of copper (Cu) and zinc (Zn) on the Cu and Zn content in feces and compost of growing-finishing pigs. A total of seventy-two LYD pigs, half barrows and half gilts, were assigned to four dietary treatments when their body weights were 30.5 ± 2.5 kg. Pigs in group A was control which was provided with the basal diet with 35 mg Cu/kg by adding the $CuSO_4$ and 120 mg or 100 mg Zn/kg by adding $ZnSO_4$ during growing or finishing stage. The pigs of groups B and C were fed basal diet with 6 and 4 mg Cu/kg and 60 and 50 mg Zn/kg by adding sulfuric and proteinate forms during growing or finishing stage, respectively. Group D were provided with the basal diet without extra Cu and Zn supplementation during growing-finishing stage. Dietary sample of each manipulation was collected during experimental period. Fecal sample of each pen was collected weekly and the concentration of Cu, Zn, nitrogen (N), phosphorus (P) and potassium (K) was analyzed. The feces of each pen were collected, weighed and stored every 2--3 days. The collected feces were used for composting subsequently at the end of feeding trial. After composting, the Cu, Zn, N, P and K concentration of compost were measured. The result showed that the fecal Cu and Zn concentrations based on dry matter basis at the growing stage increased approximately 3.0 to 3.8-fold and 7.6 to 15.3-fold, and the finisher stage increased by approximately 1.6 to 2.2-fold and 4.5 to 10.1-fold than the dietary Cu and Zn levels, respectively. The Cu and Zn concentrations increased approximately 1.21 to 1.41-fold and 1.04 to 1.13-fold in the final compost when compared with the feces-on-litter levels before composting. Besides, the Cu and Zn concentrations in the feces and compost increased when dietary Cu and Zn addition were increased.

Key words: Compost, Copper, Feces, Growing-finishing pig, Zinc.

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