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ORIGINAL PAPER

INFLUENCE OF ORGANIC VS INORGANIC SOURCE AND DIFFERENT DIETARY LEVELS OF SELENIUM SUPPLEMENTATION IN DIETS FOR GROWING PIGS ON MEAT QUALITY*

Martyna Batorska, Justyna Więcek, Anna Rekiel

Department of Pig Breeding and Production
Warsaw University of Life Sciences, Poland

Abstract

Selenium consumption in Poland is low, less than the required amount of Se for adults. The deficiency of Se may lead to many diseases. Food enriched with selenium can improve the Se status in humans. The supplementation of animal diets with selenium to may increase the selenium content in meat products. The aim of this experiment was to determine the effect of different selenium forms (organic vs inorganic) and dietary levels (0.3 or 0.5 mg kg^{-1}) on pork quality. An experiment with 45 crossbred fatteners (Polish Large White × Polish Landrace × Duroc) was conducted to determine the effect of a selenium source (organic – selenized yeast Sel-Plex vs inorganic – sodium selenite) and its dietary level on pork quality. Pigs were fed diets supplemented with 0.3 or 0.5 mg Se kg^{-1} of diet for 42 days (the second fattening period). After slaughter, meat quality parameters: pH_{45}, pH_{24}, drip loss, WHC, chemical composition, colour and Se concentration in *m. longissimus lumborum*, were estimated. There were significant differences in the pH_{24} value but the meat had no quality defects. Dietary addition of Se caused a significant ($P \leq 0.01$) increase in the ash content of *m. longissimus lumborum*. The Se form had no significant effect on drip loss or water holding capacity. The higher level of supplemental Se (0.5 mg kg^{-1} diet) improved the lightness of meat, which was darker in colour. The Se concentration in *m. longissimus lumborum* was found to increase significantly ($P \leq 0.01$) when organic selenium was added at 0.5 mg kg^{-1} in the second fattening period. The addition of inorganic (0.5 mg) as well as organic selenium (selenized yeast Sel-Plex) to diets for growing pigs had a beneficial effect on the colour of meat, which then became more appealing to consumers, but had no significant effect on drip loss and water holding capacity. Supplementing pig diets with the organic form of selenium (Sel-Plex), compared to the inorganic form, increased the Se concentration in pork meat.

Keywords: organic selenium, fatteners, pork quality.

dr hab. Martyna Batorska, Department of Pig Breeding and Production, Warsaw University of Life Sciences, Ciszewskiego 8, 02-786 Warszawa, Poland, e-mail: martyna_batorska@sggw.pl

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INTRODUCTION

Selenium is an essential trace element in the growth and development of humans and animals. Selenium protects cellular lipids from harmful effects of free radicals, has a role in the thyroid hormone metabolism, and is involved in stimulating the immune system, which increases antibody production. It is a key component of selenoproteins, glutathione peroxidase (GSH-Px), iodothyronine deiodinase, selenoproteins P and W, and thioredoxin reductase (Poovey et al. 2007, Kumar, Priyadarsini 2014). Selenium deficiency in the soil, water and plants has been observed in many regions of the world. Selenium excess or deficit in animal and human diets may lead to many diseases. Se deficiency impairs the cellular and humoral immunity of humans and animals (Bobček et al. 2008, Mehdi et al. 2013). Because Se deficiency in humans is correlated with an increased risk of cancer, it is important to ensure the high quality of food, which is the main source of Se for humans. Daily selenium requirement varies based on one's age and physical condition, ranging from 20 μg in children to 70 μg in adults. Low or deficient intake of Se (7-30 μg/day/person) has been observed in East European countries (Rayman 2008). Meat products are considered the principal source of selenium in the human diet (Ferguson 2010, Murphy et al. 2011). According to Pilarczyk et al. (2010), daily Se intake in Poland is 33-37 μg on average. Similar findings were reported by Wasowicz et al. (2003), who assessed the selenium intake in Poland at 30-40 μg. The low level of selenium in diets of farm animals, which are a source of meat, increases the risk of Se deficiency in humans. Pilarczyk et al. (2010) and Sobotka et al. (2012) believe that selenium levels in animal products can be increased by feeding Se-containing minerals to animals.

Inorganic forms of selenium were first incorporated into pig and poultry feeds in the 1980s in the USA. They are a cheap additive, but this form acts as a pro-oxidant (Spallholz 1994) and may trigger oxidative stress and increase lipid peroxidation, which is why its high dietary level can be toxic to pigs. According to Gjerlaug-Enger et al. (2014), the inorganic form of selenium added to a feed is excreted from the body and thus not effectively incorporated into the meat. The yeast *Saccharomyces cerevisiae* (Dobrzański et al. 2006) enriched with organic forms of selenium (mainly SeMet) has been approved by the European Food Safety Authority (EFSA) and authorized as a feed additive for farm animals at the maximum concentration of 0.5 mg Se kg^{-1} feed (EFSA 2008). Most commercially available selenized yeasts contain selenomethionine (SeMet), which forms 60% to 85% of the total selenium content (Rayman 2004, Esmaeili, Khosravi-Darani 2014). The selenium amino acid complex is absorbed in the small intestine via an Na-dependent system, which is related to the metabolic pathway of SeMet and selenocysteine (SeCyst) (Stoyanchev et al. 2006). Selenium given in the form of selenized yeast or selenomethionine is more effective in increasing the Se concentration in meat, which is to the benefit of the consumer (Gjerlaug-Enger et al. 2014).

The aim of this experiment was to determine the effect of different selenium forms and dietary levels on pork quality.

MATERIAL AND METHODS

The experiment included 45 crossbred pigs from Duroc boars mated to Polish Large White × Polish Landrace sows. During the finishing period (from 56 kg of body weight for 42 days until slaughter at 105 kg of body weight), fattening pigs were fed diets containing organic selenium (Sel-Plex® selenium yeast from *Saccharomyces cerevisiae* strain CNCM I-3060, Alltech USA) in group E1 or inorganic selenium (sodium selenite) in groups C and E2 (Table 1). The fatteners were fed with a complete balanced feed based on cereal meal (barley, wheat) supplied with soybean meal and 2.5% of premix with the selenium additives (Sel-Plex or sodium selenite).

All pigs were housed and fed individually with constant access to water.

Table 1

Level of selenium in 1 kg of complete diets in the experiment

Selenium source	Group		
	C	E1	E2
Sodium selenite (mg)	0.3	-	0.5
Sel-Plex selenium yeast (mg)	-	0.5	-

At the end of fattening, pigs were slaughtered at a meat plant according to the routine procedure. After 24-hour chilling of carcasses, muscle samples were collected from *m. longissimus lumborum* in the cranial direction to test the quality of meat and to determine the Se content. Measurements of pH were performed 45 min (pH_{45}) and 24 h (pH_{24}) *postmortem* on hanging right half-carcass using a Hanna HI-98240 pH meter with an FC 231D insertion electrode. Meat samples were determined for: chemical composition (according to AOAC procedures, 2005; protein and fat content in meat was evaluated with the Kjeldahl method according to PN-75/A-04018 and by Soxhlet extraction according to PN-73/A-85111, respectively), water holding capacity (WHC), drip loss and colour.

WHC was determined by Grau and Hamm (1953). Drip loss was determined using a weighed muscle sample (about 300 g) placed in a polyethylene bag under cold storage conditions (4°C) for 24 h. Drip loss was expressed as a percentage in relation to the initial weight of a muscle sample.

Meat colour (L – lightness, a* – redness, b* – yellowness) was measured with a Minolta CR-200 chroma meter at two locations on a chop with the muscle of 2 cm thickness, and the results were averaged.

Samples of meat were analyzed for total Se concentrations using the electrothermal atomic absorption spectrometry method (ETAAS).

The results were estimated by statistical analysis (SPSS 21.0). The distribution characteristics of the test were examined by the Shapiro-Wilk analysis, while differences between the groups were identified by the Kruskal-Wallis test. The average values and the standard deviation are contained in the table.

RESULTS AND DISCUSSION

Table 2 presents the quality traits of pig meat from control and experimental groups.

Table 2

Quality traits of meat from *m. longissimus lumborum* from pigs in the experiment

Specification	Group*			*P*
	C	E1	E2	
Number of pigs	15	15	15	
Chemical composition (%)				
dry matter	$28.60^{A} \pm 1.000$	27.89 ± 1.218	$27.18^{A} \pm 1.231$	0.010
crude protein	$22.13^{AB} \pm 0.938$	$23.41^{A} \pm 1.351$	$23.65^{B} \pm 0.853$	0.001
crude fat	$5.02^{AB} \pm 1.418$	$3.48^{A} \pm 1.200$	$2.49^{B} \pm 1.414$	0.001
crude ash	$1.14^{A} \pm 0.028$	$1.27^{A} \pm 0.058$	$1.04^{A} \pm 0.052$	0.001
Concentration of Se (mg kg^{-1})	$0.057^{B} \pm 0.012$	$0.145^{AB} \pm 0.017$	$0.061^{A} \pm 0.012$	0.001
pH_{45}	6.45 ± 0.214	$6.53^{a} \pm 0.232$	$6.32^{a} \pm 0.202$	0.028
pH_{24}	$5.80^{ab} \pm 0.089$	$5.90^{b} \pm 0.113$	$5.87^{a} \pm 0.066$	0.029
Drip loss (%)	5.58 ± 1.555	5.71 ± 2.010	5.54 ± 1.690	0.794
Water holding capacity (cm^2g^{-1})	16.84 ± 4.682	15.32 ± 5.617	20.40 ± 9.937	0.355
Colour meat:				
- L	$52.44^{a} \pm 3.773$	48.67 ± 5.964	$48.03^{a} \pm 4.636$	0.044
- a*	7.49 ± 1.552	8.30 ± 1.522	8.28 ± 1.663	0.225
- b*	$6.25^{Aa} \pm 0.957$	$4.90^{a} \pm 1.556$	$4.93^{A} \pm 0.965$	0.004

* Level of Se in 1 kg feed: group C – 0.3 mg (sodium selenite), group E1 – 0.5 mg (Sel-Plex), group E2 – 0.5 mg (sodium selenite);

A, *A* – values in the rows with the same litters differ highly significant at $P \leq 0.01$;

a, *a* – values in the rows with the same litters differ significant at $P \leq 0.05$.

One of important meat quality parameters is pH, the measurements of which at 45 min and 24 h *postmortem* serve to determine whether pig meat is normal (RFN) or has PSE and DFD quality defects. Changes in meat quality have an effect on water holding capacity and the associated colour lightness of the meat. In our study, there were differences in pH_{45} between groups E1 and E2, and in pH_{24} between group C and groups E1 and E2 ($P \leq 0.05$). Janz et al. (2008) supplemented growing pig diets with Se (0.3 or 0.7 mg kg^{-1}), vitamin E and CLA, after which they observed no significant differences in meat pH after slaughter and no risk of PSE. Significant negative correlations of pH_{45} with drip loss, WHC, tenderness and colour of meat were found. The pH_{45} and pH_{24} values of *longissimus dorsi* muscle obtained in our experiment were typical of normal meat (Pospiech 2000). In a study by Batorska (2013), the pH_{24} of *longissimus dorsi* muscle was not different between the organic vs inorganic Se group at 0.5 mg. In our study, there were differences in the pH_{24} value between group C and the experimental groups, all of them ranging between 5.80 and 5.90.

Drip loss from *m. longissimus lumborum* was not dependent on a dietary source or level of selenium. The drip loss values obtained in our study were characteristic of PSE- or DFD-free pork. The addition of different forms and levels of selenium to the diet had no significant effect on the water holding capacity of pig meat. Mahan et al. (1999) reported that drip loss values for the loin of pigs supplemented with 0.3 mg Se kg^{-1} were similar to those for the meat of control pigs, but the meat from fatteners receiving the inorganic form of selenium in the diet had greater drip loss from the loin compared to animals supplemented with organic selenium. Mateo et al. (2007) and Zhan et al. (2007) observed drip loss from meat to decrease linearly with the increasing dietary levels of Se. Dietary addition of the inorganic form of selenium at 0.3 mg kg^{-1} to pigs did not reduce drip loss from the meat. In a study by Svoboda et al. (2010), drip loss was highest (2.5%) from the meat of fatteners receiving selenium selenite (0.3 mg kg^{-1}) and lowest (1.91%) in the group fed diets enriched with selenized yeast. The authors concluded that selenomethionine (SeMet) found in selenized yeast is effective in strengthening cell walls, thereby improving water holding capacity and reducing drip loss from meat.

In our study, significant differences occurred in the chemical composition of *m. longissimus lumborum* from pigs. Meat from the pigs fed 0.5 mg Se kg^{-1} had a higher protein content ($P \leq 0.01$) and lower fat content ($P \leq 0.01$) compared to the control animals. In the present study, a higher mineral content of meat was characteristic of pigs from group E1 (0.5 mg Se from Sel-Plex) compared to groups C and E2 ($P \leq 0,01$), whereas the lowest ash content was found in the meat of pigs from group E2. Bobček et al. (2004) found that the use of 0.3 mg Se kg^{-1} feed had no effect on the level of protein in loin and ham muscles, but IMF content tended to decrease ($P > 0.05$) in meat from pigs receiving supplemental Se. In a study by Batorska (2013), feeding organic (Sel-Plex) vs inorganic selenium (sodium selenite) at 0.5 mg kg^{-1} to pigs in the second fattening period had no effect on the protein content of loin

(22.4-22.6%), although there was a significant ($P \leq 0.05$) difference between the groups in the level of fat in MLD, which was 2.57% and 2.01%, respectively. Increasing the fat content of meat may have a positive effect on the sensory attributes of pork by improving its tenderness and juiciness. Also SVEDAITE et al. (2009), who used organic selenium (0.2 mg kg^{-1}) together with vitamin E (20 mg kg^{-1}) in pig fattening, demonstrated that pork from the experimental fatteners was more tender (by 3.2%), contained less fat (by 0.2%), had higher WHC (by 2.9%) and was characterized by lower cooking loss (by 0.3%) compared to the meat of control pigs. Our findings confirmed the higher protein content of *m. longissimus lumborum* and the lower fat content when the higher level of Se (0.5 mg) was used, regardless of its form in the feed premix.

The colour of fresh meat and its stability are the most important quality attributes for consumers as determinants of meat freshness, healthiness and good culinary quality (KRAUSE et al. 2007, TROY, KERRY 2010). Meat colour does not coincide with culinary quality, but consumers demand that beef should be bright cherry-red, lamb brick red, and pork pink in colour (TROY, KERRY 2010). Colour instability of meat (fresh and smoked) is due to factors such as oxygen and ultraviolet radiation, which cause oxidation of myoglobin (KRAUSE et al. 2007). Meat stays red for a relatively short time because both deoxymyoglobin and oxymyoglobin are rapidly oxidized to metmyoglobin, which gives meat a brown colour; consumers perceive such meat as not fresh (TROY, KERRY 2010). MANSINI and HUNT (2005) hold that the meat colour typical of pork depends on the pH value through its effect on deoxymyoglobin and oxymyoglobin oxidation on the surface of fresh meat. There is a positive correlation between the concentration of hydrogen ions and the L value, with higher pH of meat making it darker and lower pH value making it brighter (STRZYŻEWSKI et al. 2008). In our study, the meat of fatteners receiving different forms of dietary selenium at 0.5 mg kg^{-1} was darker than that from control animals. In pigs from groups E1 ($P \leq 0.05$) and E2 ($P \leq 0.01$), there were differences in meat yellowness (b*) compared to control. No differences were found between the experimental groups in meat redness (a*). The darkening of pork colour as a result of adding organic selenium to the feed may have a beneficial effect on consumer decisions when purchasing meat with more intense colour. MAHAN et al. (1999) showed differences in meat colour lightness depending on the form of selenium. Organic Se added at 0.3 mg reduced the L value (made the meat darker) and a linear correlation was found between the L value and the amount of inorganic Se in feed towards lighter colour. A tendency ($P > 0.05$) for a more intense red colour of the meat from fatteners fed organic Se at 0.15 mg kg^{-1} of the feed was observed by POOVEY et al. (2007).

In our study, the form of selenium added to pig feeds had a significant effect on its concentration in *m. longissimus lumborum*. In the 42-day-long second fattening period, supplementing organic Se (Sel-Plex) at 0.5 mg kg^{-1} of the diet increased the selenium content of meat compared to group C and experimental group E2 (supplemented with sodium selenite) by 0.088 mg and 0.084 mg, respectively ($P \leq 0.01$). This is supported by Mahan et al. (1999), who found that feeding supplemental inorganic selenium to pigs contributed little to the increased Se level in the muscles, whereas organic selenium caused a linear increase in the muscle selenium concentration. According to Kim and Mahan (2001) and Bobček et al. (2004), replacing methionine with selenomethionine (SeMet) in selenized yeast beneficially affects the concentration of this element in the studied tissue. In a study by Olivera et al. (2005), a selenium form in pig feed (sodium selenite or Se from selenized yeast) had an effect on the Se concentration in the loin. Increasing the dietary level of inorganic Se from 0.1 to 0.3 mg Se kg^{-1} did not significantly increase the Se concentration in the tissue. Likewise in our study, inorganic Se added at 0.5 mg kg^{-1} of feed (group E2) did not significantly increase selenium deposition in *m. longissimus lumborum* in the second fattening period compared to group C (0.3 mg kg^{-1} of inorganic Se). Mateo et al. (2007) showed the Se content to be highest ($P \leq 0.001$) in the loin of pigs fed a diet supplemented with organic selenium, particularly when compared to sodium selenite added at 0.3 mg kg^{-1}. Metabolic differences between the organic and inorganic forms of selenium cause differences in its concentration in animal tissues. Improvement in the selenium content of loin was also noted by Zhan et al. (2007). Lagin et al. (2008) confirmed that Se concentration in *m. semimembranosus* and *thoracis* increased ($P \leq 0.001$) after supplementing 0.3 mg kg^{-1} of organic Se to the pig diet. The authors showed that adding organic selenium to pig feed had the benefits of increasing Se retention in the tissues, minimizing the risk of PSE meat, reducing cooling loss and improving the nutritive value of the pork. Different results were obtained by Lisiak et al. (2014), who compared the use of different forms of Se in pig diets (from 60 kg b.w.) and showed selenium levels to be higher in *biceps femoris* ($P \leq 0.01$), *semimembranosus* ($P \leq 0.01$) and *triceps brachii* muscles for inorganic selenium. The addition of selenized yeast to a pig diet had only increased Se concentration in *m. longissimus lumborum* ($P \leq 0.01$).

Morel et al. (2008) concluded that 100 g of such enriched pork contains 0.20 μg Se and may provide one-third of the recommended daily allowance of this element for humans. In a study by Gjerlaug-Enger et al. (2014), supplementing organic Se increased its concentration in meat up to 0.3 mg kg^{-1} and resulted in about 53 mg Se in a portion of pork (175 g), which provides 75% of the daily Se requirement.

Mateo et al. (2007) believe that the organic form of selenium added to a pig feed may improve pork quality and additionally contribute to a higher consumption of this microelement by consumers. According to Jang et al. (2010), every organic source of selenium should be thoroughly investigated before being used in animal feeds. In addition, it is necessary to determine the period during which a given form of selenium will complement dietary rations for animals so as to maximize selenium retention in tissues or to obtain selenium-enriched animal products that are functional foods.

CONCLUSIONS

The addition of inorganic (0.5 mg) as well as organic selenium (selenized yeast Sel-Plex) in diets for growing pigs retained the darker colour of meat desired by consumers, without having significant effects on drip loss and water holding capacity.

Supplementing the diets with the organic form of selenium (Sel-Plex) compared to the inorganic form resulted in a significantly higher Se concentration in pork meat.

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