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Review Article

Dietary vitamin C, pig performance and pork quality during stress – A review

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ABSTRACT: Historically, vitamin C was discovered as a result of scurvy disease. Vitamin C deficiency or scurvy is a very old disease of civilization. In the past, it was a very difficult problem when humans were under conditions where they could not have access to either fresh fruit or vegetables and incidences of scurvy were very common. Later, it became obvious that humans would not develop scurvy if they consumed a small amount of fresh vegetables or fruits or even drank some citrus juice. Between 1907 and 1912, Holst and Frohlich in Norway demonstrated that scurvy could be produced in the guinea pig and could also be cured by feeding various fresh vegetables and fruit; however, that factor or active ingredient was destroyed by heat and drying. These observations therefore confirmed earlier opinions obtained from observations in humans. More importantly, the latter observations thus provided a laboratory animal model for the study of scurvy. Consequently, this resulted in the isolation of vitamin C also known as ascorbic acid (AA) in 1933. Following its discovery and isolation, vitamin C has been shown not to be a cure for scurvy only but has been shown to be very useful in the overall health of laboratory and domesticated animals, such as pigs. It has been implicated in being useful in pig production, especially during stress. This paper examined some of the production areas of vitamin C needs and its ameliorative capacity in serving as a succour to the pig during stress. There are many areas of pig production that AA plays vital functions. Some of the areas AA is involved in alleviating stress are: in the reproductive capacity of the pig, up-regulating the pig's immune system as well as improving the quality of pork for better value capture. Here, it is demonstrated that AA can be used in enhancing the overall productive indices in the pig during stress.

Keywords: Pig, pork quality, productivity, stress, Vitamin C.

INTRODUCTION

Pigs are fast-growing animals with short gestation periods leading to quick profit turnovers. Their fast-growing characteristics often result in the sudden death syndrome due to their rapid growth rates (NRC, 2012). The attendant effect of this syndrome often gives rise to a reduction of the hog farmer's profit margin. This situation is worse for pig farmers in the tropics due to stress, such as heat stress pigs undergo as they are deficient in sweat glands that help reduce the pig's heat stress (Argenzio and Monteiro-Riviere, 2000). It is common knowledge that pig wholesomeness relies on multifarious integrated factors. It is also known that diets play critical physiological functions in the maintenance of animal health and thus prevention of disease factors, such as nutritional/environmental diseases and stress, particularly heat stress. These factors have also been implicated in intensifying sudden death syndrome in pigs (Argenzio and Monteiro-Riviere, 2000; NRC, 2012).

To this point, therefore, nutrition remains a fundamental key in the prevention-modulation reflecting a specific accent in the diet as an essential means of preserving the animal wholesomeness and productivity. To this extent, nutritional science and technology have to move towards the development of strategizing for micro-nutrients such as the antioxidant vitamins for productivity improvement parameters, such as reduction of the negative effects of

environmental stress, including heat stress on the pig for optimal productivity, especially in the tropics where heat stress is endemic, particularly during the dry or summer periods (Argenzio and Monteiro-Riviere, 2000; NRC, 2012). Micro-nutrients, such as vitamin C play some special major roles in health-related conditions in the animal during stress and thus are involved in ameliorating the negative impacts of stress on the pig via prevention or significantly diminishing such effects and positively impacting productivity (Johnson *et al.,* 2019b).

Vitamin C also known as ascorbic acid (AA) was discovered in 1933 (Harworth and Hirst, 1933). Thus, it is used interchangeably in this paper. Since AA discovery, it has been shown to be very important in improving animal health, including the pig (Johnson and Popoola, 2020). Many independent studies have also shown that since the discovery of vitamin C, it has been found to have many functions. Vitamin C serves as a cofactor for some oxygenases which are involved in the synthesis of catecholamines and carnitine and also in the metabolism of cholesterol, xenobiotics and tyrosine (Combs, 2008). Vitamin C also functions in the recycling of Vitamin E (May *et al*., 1998; NRC, 2012). Vitamin C protects the immune system and facilitates the conversion of cholesterol into bile acids thus lowering blood cholesterol levels. Cholesterol is a major factor that triggers atherosclerosis. AA has successfully been used as a succour in atherosclerosis (McRae, 2008). Also, it functions to increase gut absorption of iron by reducing ferric iron to ferrous iron (Wollenberg and Rummei, 1987; Combs, 2008: Matsui, 2012). To these points, therefore, this paper aims to elucidate the roles of vitamin C in pig productivity in the presence of stress conditions in a literature-based fashion to enable their adoption in regions where stress poses problems in pig production.

PIGS IN STRESSFUL CONDITIONS AND VITAMIN C REQUIREMENTS

According to Combs (2008), swine and ruminants can synthesize ascorbic acid fully from glucose in the liver or kidney to meet normal daily needs. However, pigs under certain environmental conditions need to be given vitamin C. For instance, during periods of stress, such as excessive heat during the dry season, especially in the tropics, early weaning and disease challenges, body stores of vitamin C can be quickly depleted. The drop in plasma concentration is evidence that there is either insufficient biosynthesis of vitamin C during periods of stress or there is an increased requirement for ascorbic acid to alleviate the negative effects of stress factors. Vitamin C supplementation in swine nutrition has shown to be beneficial in post-weaning diets; and in lactating sows to help combat the negative effects of stress, such as heat stress on feed intake. Again, it has also been found in recent studies that vitamin C can be used to improve semen quality during heat stress (Lechowski *et al.,* 2016). This thus implies that vitamin C can be employed to improve the reproduction traits in boars.

Zhao *et al*. (2002) studied the performance, iron status and immune function of weaned piglets on diets supplemented with vitamin C and found that vitamin C supplementation did not improve growth rate, feed intake or feed conversion ratio but plasma iron concentration increased with vitamin C supplementation. They also reported no significant increase in bovine serum albumin. From the study, they deduced that weanling pig performance is not improved as a result of vitamin C supplementation and advocates for further studies to find out whether or not vitamin C plays a role in stimulating humoral immune function in pigs as results could not completely rule out the possibility that such a role exists.

Hanczakowska *et al.* (2005) reported that the use of high doses of vitamins C, E and beta-carotene in pig diets had positive effects on daily weight gains and feed conversion ratio. All vitamins used in the study, including vitamin C, demonstrated a reduction of cholesterol in the loins of the pig and improved the water-holding capacity of the pork suggesting that vitamin C can be used to improve meat quality; a desirous meat quality that elongates the shelf-life of pork quality for higher value capture.

Additionally, Zhou *et al.* (2021) evaluated the antioxidant activities of four antioxidants *in vitro*, namely: ethoxyquin (EQ), butylated hydroxytoluene, α-tocopherol (vitamin E) and L-ascorbic acid (Vitamin C) and vitamin C was found to have better antioxidant capacity supporting the fact that vitamin C is an antioxidant vitamin that improves the health of the animal and thus enhanced its productivity indices, such as growth rate, feed conversion ratio and carcass quality with improved water holding capacity.

These workers also evaluated the effects of the different antioxidant activities in their studies on growth performance, immune function and antioxidant capacity of weaned piglets at 30 days of age. The results showed that pigs' diets supplemented with vitamin C demonstrated significantly higher final body weight and average daily gains. Furthermore, the levels of immunoglobulin G (IgG) and glutathione peroxidase in the vitamin C-supplemented diet group were significantly higher compared to the control group. The malondialdehyde (MDA) content was also significantly lower in the serum of the vitamin C diet group animals at the end of the study compared with the control and other treatment groups suggesting that the level of exposure to stress, such as nutritional and environmental stresses were least in the vitamin C animals. MDA is usually used to measure stress levels in animals exposed to stress (Johnson and Popoola, 2020). In the same study, the levels of immunoglobulin A (IgA) and total antioxidant capacity in the Vitamin C group animals again were significantly higher compared to other treatment groups, including the control. This also demonstrated that the vitamin C group animals had improved growth performance, antioxidant capacity and

immune functions compared to the control and other treatment groups of the weaned pigs in the study. These observations further support the fact that vitamin C, an antioxidant vitamin can be used in improving pig productivity during stress.

Vitamin C and reproduction in pigs

Lechowski *et al.* (2016) studied the effect of vitamin C on indicators of gilts and sows reproductive value using 64 *Pulawska* breeds of gilts. In the study, the experimental gilts were given 2.4 g vitamin C supplements daily throughout the experimental period. The number of corpora lutea and the state of development of the reproductive organs were determined at the third estrus of the experimental gilts. The results showed that gilts fed supplemental vitamin C were characterized by higher potential fertility as well as reared more piglets per litter. Though the body weight and back-fat thickness of sows during the first reproduction cycle in the control and experimental groups were reported to be statistically non-significant; the piglets in the experimental groups fed supplemental vitamin C had higher body weight in the 1st and 21st days of rearing. Larger contents of protein, immunoglobulins, and vitamin C were recorded in the colostrum and milk from experimental sows fed supplemental AA. From the findings in the study, it was concluded that supplementing the diet of gilts and sows with AA improves reproductive performance and thus vitamin C can be effectively used as a means of preventing or controlling the negative effects of stress, such as environmental and heat stresses in the reproductive pig.

Vitamin C in the immune response of pigs

It has been demonstrated that the addition of 150 mg of vitamin C/kg of a diet containing zearalenone produced by species of *Fusarium* fungi that occur in various kinds of cereal and feed ingredients can cause serious health hazards to plants, animals and humans, especially by impeding growth rate and reproduction, particularly in piglets can be significantly ameliorated by vitamin C. Specifically in the pig, zearalenone is a virulent mycotoxin that causes feed refusal in the pig and thus impedes growth and other performance parameters (D'Mello*et al.,* 1999). To this point, vitamin C has been used to prevent deformities in the vulva, decrease in immune response capacity, changes in serum biochemical indicators and disorders in hormone levels in piglets (Su *et al.,* 2018). By the findings of this study, therefore, vitamin C can be employed in the prevention of health challenges associated with zearalenone in the pig as a quencher of stress induced by zearalenone. Furthermore, it is an indication that zearalenone-infested grains can be converted to feed pigs when supplemented with vitamin C at least at the rate of 150 mg of vitamin C/Kg of the diet without impediments on pig growth, productivity and other performance indices in the pig, including piglets. One of the major means triggering vitamin C efficacy in these observed data would have been its role in upregulating the animal immune system (Johnson *et al.,* 2019a; Johnson *et al.,* 2019b).

Again, according to the data findings of Johnson and Popoola (2020) that demonstrated that the ingestion of dietary vitamin C at the level of 100 mg/kg of diet upregulated the total antioxidant power of the animal, including all antioxidants' enzymes investigated, such as catalase, glutathione, superoxide dismutase and glutathione-peroxidase. Vitamin C in the same study was observed to have simultaneously significantly reduced MDA levels compared to the control. Furthermore, it was demonstrated in the study that vitamin C efficacy in these functions was further enhanced when combined with vitamin E probably due to the synergy identified to exist between them (Nuttall *et al.*, 1999; NRC, 2012). These are some of the strategies for the use of vitamin C in mitigating stress in pig production thereby enhancing their productivity.

Vitamin C and pork quality

Ascorbic acid improves pork quality. Pion *et al.* (2004) studied the effect of Vitamin C supplementation on plasma ascorbic acid and oxalate concentrations and its effect on pork quality. At the end of the study period, it was observed that supplemental vitamin C increased plasma ascorbic acid concentrations but did not affect oxalate or cortisol levels. Muscle ascorbic acid and lactic acid were not affected. From the study, it was found that on-farm supplementation of vitamin C was generally not effective in improving pork quality, which may be related to timing relative to slaughter. Hanczakowska *et al.* (2005) reported that vitamin C was the least efficient in improving daily weight gain, feed conversion ratio and meat quality of pigs compared with Vitamin E in a study on the effect of natural antioxidants (vitamin E, C and beta-carotene) on productivity and meat quality.

However, the study of Johnson *et al*. (2019b) showed that vitamin C improved pork quality as measured by serum levels of xanthine oxidase, cortisol and MDA. Nevertheless, improvement in pork quality was further improved when dietary vitamin C was combined with vitamin E probably because of their additive effects since both of them are known antioxidant vitamins. It has been demonstrated that vitamin C shows strong synergy in its antioxidant properties in the presence of vitamin E. This might not be unrelated to the ability of vitamin C to regenerate vitamin E thereby intensifying their synergistic antioxidant effects. These synergistic activities of vitamin C with vitamin E significantly reduce stress on the animal and thus enhance their productivity (Salonen *et al.,* 2000).

CONCLUSION

From the fore-discussed, vitamin C plays important roles in alleviating the negative effects in pigs that are reared under stress-related conditions, such as environmental stress, post weanling stress, amongst others. Utilization of vitamin C increases during periods of stress, but its synthesis is limited. Vitamin C enhances feed intake, body weight gains and feed conversion ratio. In the overall, therefore, vitamin C improves productivity parameters in the pig. Thus, it should be employed in pig production as shown by the findings of independent studies. It should also be noted that vitamin C efficiencies in these functions are dose-dependent depending on the pig's physiological status, such as piglets, weanling pigs, growing and reproductive gilts and sows. The combination of vitamins C and E has also been shown to further enhance productivity during stress.

CONFLICT OF INTEREST

The authors declare that they have no conflict interest.

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