AN EVALUATION OF JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS L.*) UTILIZATION AS A BENEFICIAL FEED INGREDIENT TO MITIGATE HEAT STRESS IN PIGS

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Abstract

It is very important to understand, quantify and mitigate the physiological impact of heat stress in pigs. For pigs, the thermal comfort zone temperature ranges between 18 and 25°C. Thermal stress negatively affects the function of the intestinal barrier, inflammatory response, postabsorptive metabolism, directly affecting growth performance and carcass quality causing a serious acid-base imbalance, poor feed conversion, low nutrient intake and high mortality. Jerusalem artichoke (Helianthus tuberosus) is a valuable plant resource due to its yield (10-15 t/ha of tuber production), and a functional food ingredient with nutraceutical properties due to its chemical composition, mineral and vitamin profile, and antioxidant activity. It is a highly productive and easily grown crop that can last for years into soil. It is also a beneficial prebiotic source with a high inulin content (75% of the carbohydrate complex). Jerusalem artichoke tubers can be administered fresh or powdered with positive effects on intestinal microflora. Jerusalem Artichoke improves the microbial content and the defense and regeneration process of the gut. This study aims to achieve a comprehensive analysis of the importance and need of using Jerusalem artichoke as a beneficial and affordable feed ingredient in combating the negative effects of heat stress on pigs.

Key words: *Jerusalem artichoke, pigs, heat stress, inuline, intestinal microflora*

INTRODUCTION

Increasing temperature as a result of greenhouse gas emissions within our century is literally a hot subject which has determined physiological and behavioral changes to humans and animals (Galán et al., 2018). Studies run out on different species over several decades observed that a “phenotypic plasticity” phenomenon appeared which allows to individuals the ability to adapt their behavior, morphology, physiology as a response to modified environmental conditions (Bradshaw and Holzapfel, 2006). Heat stress is caused by a complex combination of air mass circulation, temperature, humidity and solar radiation and it appears as a consequence of body struggling to adapt to altered climate temperature (Mader et al., 2006). To maximize the radiant heat dissipation, the heat stressed animals will redirect the blood to periphery helped by the gastrointestinal tract vasoconstriction, therefore causing a decreased intestinal integrity and increased endotoxin levels. (Lambert, 2009). According to Stewart and Cabezon (2016) the thermoneutral zone in pigs depends on production phases: 32-38°C for newborn piglet, 21-27°C for nursery (13-22 kg), 15-21°C for nursery (23-35 kg), 24-30°C for weaner category, 10-21°C for lactating/gestating sows, boars, growing/finishing pigs. As Mayorga (2018) stated the heat stress affects greatly the production parameters, the physiological and animal status welfare: decreased feed intake, reduced nutrient absorption, smaller gain weight, increased body temperature, lower milk production for lactation sow, increased

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mortality percentage for all categories (embryo included). Considered as an important source of carbohydrates the Jerusalem artichoke (*Helianthus tuberosus L.*) tubers lost their importance after the potato introduction in Europe (*Solanum tuberosum L.*). In particular, the fructo-oligosaccharides and inulin content of Jerusalem artichoke powder varies from 61% to 85%, depending on factors as genotype, climate, soil, irrigation level and harvesting period (Krivorotova et al., 2014, Aduldecha et al. 2016).

The purpose of this review was to find and highlight the benefits of dietary Jerusalem artichoke (*Helianthus tuberosus L.*) utilization in animal feeding, especially on pigs reared under heat stress.

MATERIALS AND METHODS

We used the study's keywords on Google Academic, MEDLINE®, PubMed® and we accessed or cited articles/reviews concerning Jerusalem Artichoke (Helianthus tuberosus L.) scientific topic. Romanian and English language limitations were applied to this search. A number of 57 scientific paper were consulted and main information concerning our subject were cited within the manuscript.

Nutritional value of Jerusalem Artichoke (Helianthus tuberosus L.)

The Jerusalem artichoke is considered to be a valuable food, medicinal plant and important fodder due to its rich source of inulin, fructose and pectin and it is cultivated in several countries, especially in those with a temperate climate (Koroleva, 2020; Krivoshapkin, 2020; Safarmadi, 2020). Jersualem artichoke was first cultivated to North America, and introduced into Europe in 1607. Growing so fast within wild areas, sometimes the plant was considered a weed. Potential advantages of Jersualem artichoke include profitable by-products as sustainable biofuel and biochemical production and cheap inputs (Li et al., 2013). Jerusalem artichoke can be administered to livestock as green mass, hay or silage therefore increasing the production efficiency without neglecting its nutritional value, sometimes exceeding certain crops Berzhanova (2019). Despite its high carbohydrate, amino acid, and dry matter content (22–32%) Jerusalem artichoke green mass feed value is low in fiber, making it an excellent source of high-energy feed, exceeding legumes and corn in terms of energy content (Kotova, 2015). Compared to other commercial crops, Jerusalem artichoke thrives well on different type of soils, including those poor on nutrients, it has a high reproduction rate, good persistency to frost, drought and salinity, hardy to plant diseases, using less fertilizer (Gunnarsson et al., 2014). Both, the aerial and tuber biomass chemical composition contain dietary fiber, protein (an equilibrated amino acid composition), vitamins (B and C), minerals (magnesium, iron, zinc, silicon), fatty acids (Kuznetsov, 2007). A free-range foraging system using alternative crops as lucerne, Jerusalem artichokes and grass-clover for sows and growing pigs can represent a feasible strategy to reduce the Green House Gas (GHG) emissions per kg pig produced but only applying other management production strategies (reduced stocking density, strip grazing, production during the crops' growing season) in terms of reducing N leaching as well (Jakobsen, 2018). As Sawicka et al. (2021) stated the Jerusalem artichoke tubers quality is determined mainly by their chemical composition. The authors noticed a high variability of nutrients due to the soil and climatic conditions when assessing the chemical composition of Jerusalem Artichoke tubers: 22.59-22.53 % dry mass; 18.79-18.97 % soluble dry mass; 15.60-18.72% inulin; 3.47-5.42% crude fiber; 0.22-0.18% crude fat; 9.43-11.50% crude protein; 7.25-6.18% true protein; 46.67-48.48 (g/kg^{-1}) total amino acids; 5.40-5.42 ($mg/100\ g^{-1}$) ascorbic acid; 10.19-12.48 (g/kg^{-1}) N; 6.16-3.42 (g/kg^{-1}) P; 28.36-31.81 (g/kg^{-1}) K; 1.50-1.79 (g/kg^{-1}) Mg; 0.64-0.85 (g/kg^{-1}) Ca; 0.16-0.20 (g/kg^{-1}) Na. As, Wang et al. (2020) stated the whole plant Ca content (10%-17% DM) is similar if not higher to that of alfalfa (6% -15% DM), corn straw (2% to 7% DM), and ryegrass (6% to 8% DM) and the P content ranges between 0.16% to 0.45% DM. Harmankaya et al (2012) analyzed the mineral content of wild Jerusalem artichoke and found high concentration of potassium

(21615 -26251 mg/k), phosphorus (2585-4791 mg/kg), zinc (11-15.6 mg/kg), calcium (1573-2073 mg/kg), and manganese (1707-2141 mg/kg. The high content of potassium is beneficial considering that ionic and water balance depends on it. According to Cardellina (2015) Jerusalem artichoke tubers presents high amount of vitamin C (7 -26 mg/100 g DM), carotenoids (48-131 mg/100 g DM), folic acid (53-87 µg/100 g DM). The Jerusalem artichoke tubers contain little amount of starch, fat, and low concentration of monounsaturated and polyunsaturated fatty acids, ideal source of dietary fiber due to the inulin presence (Afoakwah et al., 2015). The leaves and flowers of Jerusalem artichokes are an excellent source of bioactive compounds with antioxidant, antibacterial, anti-inflammatory properties. Showkat et al., (2019) noticed that the total phenolic content (72–82% chlorogenic and dicaffeoylquinic acids from leaves and tuber extracts) was higher when determined within leaves compared to flowers and stem. Presenting all these attributes and qualities it is difficult to understand why is still an underexploited resource for humans and animal.

Prebiotic and probiotic potential of Jerusalem artichoke

The prebiotic influences positively the gut metabolism enhancing the immune system. Samal et al. (2015) confirmed that Jerusalem artichoke powder (20, 40 and 60 g kg^{-1}) shown prebiotic efficiency after conducting a 12 weeks experiment on rats. Blood parameters, hemoglobin, glucose level, urea, calcium were significantly improved on diets supplemented with Jerusalem artichoke groups. Also, a significant increase large intestine length and a higher cecal crypt depth were noticed. The lactate and total volatile fatty acids concentrations were higher in experimental groups. Certainly, the inulin high content of polyfructose type reduces blood glucose and improves gastrointestinal functions (Lightowler et al., 2018; Wilson and Whelan, 2017). The dietary fibers such as inulin helps promoting the beneficial bacteria such as Bifidobacterium and Lactobacillus found within large intestines, repressing other harmful microorganisms. Due to the antibacterial specific activity of bifidobacteria (fermenting inulin) and lactobacilli, a reduced number of fecal bacteria was observed within diets supplemented with inulin and fructooligosaccharide (Gibson and Wang, 1994). There is evidence that short-chain fatty acid butyrate resulted from inulin and fructooligosaccharides fermentation reduces colon cancer incidence (Pool-Zobel et al., 2002). The high fructans level of Artichoke jerusalem tubers has led to its acceptance as a functional, probiotic food and also as a prebiotic additive with beneficial effects on intestinal morphology and blood metabolites (Samal et al., 2015). Studies confirmed that inulin is a non-digestible oligosaccharide, utilized by lactobacilli and bifidobacteria, with prebiotic effect, able to modulate the intestinal microflora, environment and the immune response, therefore improving animal performance (Kaur and Gupta, 2002; Gibson et al., 2004). When testing 4% dried Jerusalem artichoke tubers with /without a prebiotic addition on an 40 days experiment, on pigs from 10 day of life, Barszcz et al. (2016) observed an increasing level of cecal valeric acid and Bifidobacterium spp. in the proximal and distal colon, as well as a decreasing level of isoacids, β-glucosidase and β-glucuronidase activity within the colon. Valdovska et al., 2014 considers that inulin manipulation of intestinal microflora can be realized by inhibition of binding pathogens on the mucosal intestinal surface due to the inulin to lectin specific binding on the pathogen cell' surface. On the other hand, Kaur and Gupta (2002) stated that the bacteria presented within colon can digest inulin and use it to obtain volatile fatty acids, lower the intestinal pH, therefore inhibiting E. Coli and Salmonella.

Jerusalem artichoke as potential valuable feed ingredient

Jerusalem artichoke is considered an alternative forage with high nutritional value and valuable beneficial growth characteristics (crude protein, crude fiber, and calcium in the optimal harvest period of forage-type the straw are comparable to alfalfa hay at the full bloom stage or the ryegrass straw and corn at the mature stage). Also, Jerusalem artichoke presents a strong environmental adaptability and it is a functional ingredient with prebiotic effects in the gastrointestinal tract of monogastric animals and young ruminants. Hay and Offer (1992) noticed that Jerusalem artichoke has a high-quality roughage potential with thin and fragile leaves and small breakable particles which determines a rapid rumen degradation and absorption. In vitro experiments on horse and ruminant rumen fluids, Jerusalem artichoke in vegetative phase increases dry matter and true organic matter loss (Ersahince and Kara, 2017). Other authors stated that alfalfa partially substituted by dietary Jerusalem artichoke may increase the dry matter intake due to a high palatability and acceptability (Papi et al. 2019). When mixing corn or Lactobacillus together with Jerusalem artichoke the ensiling process is enhanced (Kononoff et al., 2003) and a satisfactory digestibility and a weak acidogenesis of silage is assured for ruminants (Koczon et al., 2019). Razmkhah et al. (2017) evaluated on sheep for 31 days the partial substitution of corn with Jerusalem artichoke silage (up to 540 g/kg of DM) and noticed a slight increasing of blood urea and total ruminal volatile fatty acids and a decreasing of N retention. Also, Papi et al. (2017) substituted the maize silage with Jerusalem artichoke silage (up to 200 g/kg DM) on fat-tailedlambs' diet, with no adverse effect on production performance, ruminal fermentation and blood parameters. Jerusalem artichoke was included in fish meal at a rate of 5.0 and 10.0 g/kg with positive results on the growth performances, survival rate and immune status of Nile tilapia fingerlings (Tiengtam et al., 2018). Yildiz et al. (2006) evaluated the effects of 5% Jerusalem artichoke, 5% Jerusalem artichoke + 5% vetch and 10% Jerusalem artichoke + 10% vetch on production performances, egg quality and cholesterol content in laying hens. Although the live weight of 10% Jerusalem artichoke + 10% vetch was lower compared with the other groups, the feed efficiency was significantly improved. When including Jerusalem artichoke silage is recommended to be done gradually, daily depending on species: cattle (25–45 kg); sheep and goats (3–5 kg); pigs (3–8 kg); horses (8 kg); rabbits, (0.25 kg); poultry (0.04–0.25 kg) (Korolev et al., 2007; Khaziakhmetov, 2019). Adding topinambur in broilers' drinking water influenced positively the production performances, a higher live weight on day 35 of the experiment, lowered the level of bacterial endotoxin levels, and reduces the pathogens in ceca Kleessen et al. (2003). According to Park and Park (2012) dietary inulin (250 mg/kg diet) supplementation increased poultry egg production and weight. A 1% inclusion of 1% inulin improved laying hens´ egg production Chen et al. (2005).

Jerusalem Artichoke in pigs' diet

Pigs are excellent models for human intestinal physiology, and therefore many probiotic studies have been done with them. Itis critical to enhance the dietary nutrients metabolic utilization a gut health (Willing et al., 2012). Jerusalem artichoke tubers being a major source of fructans (inulin and fructooligosaccharides) can contribute to a better feed eficiency due to a well-balanced microbiota, especially on piglets. Fructooligosaccharides are oligosaccharides that influences blood glucose positively due to a plasma-free fatty acids high level when using low tissue glucose and gut bacterial fermentation of fructo-oligosaccharides to short-chain fatty acids and bacterial modulation of bile acids, both interacting with host metabolism (Le Bourgot et al., 2018). According to Fukuyasa et al. (1987) fructooligosaccharides included in piglets' diet improved body weight and feed conversion efficiency parameters. Flickinger et al., (2003) observed that in weanling category the dietary fructooligosaccharides increases bifidobacteria incidence within the large intestine. Also, the prebiotic effect on intestinal absorption may vary depending on animal species and prebiotic. The prebiotics may also affect immune function. Some studies found that the presence of dietary fructooligosaccharides in growing pigs category decreased fecal mass, volume and slurry malodor due to an important fermentation at large intestinal level (Flickinger et al., 2003; Kotchan and Baidoo, 1997). Additionally, a reduced level of E. coli and Clostridium spp. within pigs' colon and clostridia, enterobacteria, and enterococci within feces were observed by Flickinger et al., (2003) and Bomba et al. (2002) using dietary inulin supplements. A study (2006-2008) used different roughages as: silages, ryegrass, Jerusalem artichoke, turnip for fattening pigs (Maria Sappok, 2008). Farnworth et al. (1992) fed 1.5 % Jerusalem artichoke tuber flour to weaned pigs for 4 wk and noticed no change concerning feed intake, feed efficiency, body-weight gain, volatile fatty acid levels and microbiological profile. In an experiment trial conducted on Jerusalem artichoke tubers composition and digestion in the pig’s gastrointestinal tract (fitted with intestinal cannulas) was studied. The study concluded that about 50% of the fructans were degraded anterior to the duodenum, and less degradation occurred during passage through the small intestine. The digestion of 40% of tuber dry matter occurred to the terminal ileum. Kuznetsov (2007) reported that Jerusalem artichocke could be the optimum feed for pigs and suckling pigs under 60 days, taking into consideration that bifidobacteria and lactobacilli are the main bacteria provided by the sow milk (Herich et al. 2002). Also, Böhmer et al. (2005) concluded that inulin degradation occurred within upper small intestine due to its high number of microorganism.

CONCLUSIONS

Jerusalem Artichoke is gaining popularity due to its multiple beneficial effects observed. Also, it can be considered a valuable available food and feed resource, that meets required challenges and benefits, especially when a depletion and scarcity resources is globally encountered. The contribution of Jerusalem artichoke tuber on microbial and immune status on pig’s intestine begins to attract considerable attention, but it is necessary to explore more the degree to which the plant may alleviate the negative effects of heat stress on pigs.

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