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Effects of a Phytogenic Feed Additive on Redox Status, Blood Haematology, and Piglet Mortality in Primiparous Sows

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Abstract: This study aimed to investigate the effects of a polyphenolic phytogenic feed additive (PFA) based on plant extracts, such as *Embelia officinalis*, *Ocimum sanctum* and nut fibre, on the redox status, haematological parameters, and piglet mortality in sows. A total of 64 primiparous sows were divided into two groups: T1-control group: regular gestation (GF) and lactation feed (LF), T2 group: regular GF and LF supplemented with a PFA (10 g daily) for 14 days before and 7 days after the farrowing. Blood samples were collected 0–3 h after farrowing. Haematological parameters (Packed Cell Volume/PCV, White Blood Cells/WBC, Platelets/PLTs) were counted in blood smears. Thiobarbituric acid reactive substances (TBARS) and protein carbonyls (CARBS) levels were determined in sow plasma. The performance and reproductive parameters of sows at farrowing and weaning days were recorded. The mean numbers of PCV and PLT counts in the T2 group were higher in comparison to the T1 group (p = 0.041, p = 0.033, respectively). In contrast, the mean numbers of WBC and neutrophils were almost significantly higher in the T2 group (p = 0.051). The mean number of stillborn piglets was significantly higher in the T1 group (2.12) compared to the T2 group (1.03). The mean number of alive piglets 24 h after farrowing and the mean number of the weaned piglets were significantly higher in group T2 (13.9 vs. 15.4 and 12.6 vs. 14.3). Sows in group T2 had significantly more backfat at weaning than the sows in group T1 (13.3 vs. 12.7). The mean levels of CARBS (nmol/mL) and TBARS (μmol/L) in group T1 (24.8 and 18.7) were significantly higher in comparison to group T2 (18.3 and 14.9). In conclusion, the use of a polyphenolic PFA in sows has beneficial effects on their welfare and performance due to its antioxidative effects. Furthermore, PFAs appear to exert antithrombotic, anti-inflammatory, and protective effects on PLTs, WBCs, and RBCs, respectively.

Keywords: haematology; mortality; phytogenic; pig; protein carbonyls; stress; TBARS

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1. Introduction

Pregnancy is a high metabolic demand period for the sow, and oxidative stress is a crucial consequence [1]. Generally, free-radical production is associated with many reproductive disorders; therefore, reducing free radicals is a key strategy for farrowing sows to maintain their reproduction and lactation performance [2,3]. During the late pregnancy

and lactation stages, sows start suffering oxidative stress induced by severe metabolic burden and do not fully recover until the weaning period [3,4]. Affected sows by oxidative stress during the perinatal period may have reduced feed intake, reproductive disorders (e.g., abnormal foetal development, abortion), decreased reproductive performance (e.g., total litter size, live litter size and litter weight gain) and decreased milk production, which further affects the growth of piglets [2,5].

Generally, most studies focus on stress consequences on the weaning and finishing stage, while limited amount of studies in the literature are available on the impact of stress on farrowing sows or the effects of chronic stress on their health and welfare [6–9]. The consequences of chronic stress could be estimated based on performance, behavioural, and physiological parameters [10]. For example, decreased reproductive performance can be a symptom of chronic stress, as appropriate energy resources are not utilised for maintenance and developmental needs during pregnancy [11–13]. Moreover, chronic stress also leads to immunosuppression and is more sensitive to diseases [14,15]. Farrowing sows could experience chronic stress for an extended period [16–18], inducing negative effects not only on the sow's health and metabolism but also on foetal development and offspring's survival [19]. This is known as prenatal stress and could have negative implications on the health, welfare, and growth performance of newborn piglets [20].

Piglet perinatal and pre-weaning mortality is an economic, welfare and environmental concern [21–23]. Piglet pre-weaning mortality is a major economic and welfare issue in pig production, varying between 10.7% and 15.3% [24,25]. It depends on various factors (genetic background, litter size characteristics, gestation period, animal technician supervision, production system, and nutrition), but the main causes included suffocation, starvation, low viability and crushing [26–33].

In addition to the oxidative stress of sows in the post-farrowing period [34,35], they can also suffer from pain (uterine contractions, piglet expulsion and inflammation of the uterus during the birth of the piglets) [36]. As a result, the piglets' welfare and subsequently their survival and growth rate are compromised [35,36]. Under field conditions, non-steroidal anti-inflammatory drugs (NSAIDs) are suggested as treatment in the farrowing sows for the improvement of their health, welfare, and performance [37–42]. During the last decade, PFAs based on plant extracts have been widely proposed for administration in sows [43–45]. PFA is based on plants that are rich in antioxidants, including phenols, flavonoids, flavanols, vitamins C and E, beta-carotene, zinc, and selenium, which have been shown to have antioxidant potential [45]. Polyphenols are the most common substance [14,46] with beneficial effects for gestating and lactating sows, as they can beneficially regulate the placenta and mammary glands of sows, thus resulting in improved growth performance of offspring piglets [47]. Even if the beneficial effects of PFA administration in pigs have been previously reported, the study of their effect on stress in farrowing sows is limited [2,48]. Previous studies reported the beneficial antimicrobial, antioxidative, and growth-promoting effects of PFA substances (spices, herbs, or extracts) as feed supplements in pigs [49–53]. The tested PFA in our study is based on plant extracts with high antioxidant activity to reduce oxidative stress, such as *Embelia officinalis* [54,55], *Ocimum sanctum* [56,57] and nut fibre [58–60].

Oxidative stress is used as an indicator imbalance between the production of reactive oxygen species (ROS) in the pig's organism and the ability of the antioxidant molecules to neutralise them [61]. Several markers of oxidative stress are currently available, such as thiobarbituric acid reactive substances (TBARS), which have been used extensively as markers of lipid peroxidation, as well as protein carbonyls (CARBS), which is the most frequently used biomarker of protein oxidation in epidemiological and clinical studies [62–67]. Plasma is easily obtainable from animals and contains both lipid and protein components that may be susceptible to oxidation, making it appropriate to investigate the suitability of plasma oxidation variables as biomarkers of in vivo oxidative stress [67]. Plasma concentrations of TBARS and CARBS can be used as redox biomarkers in growing pigs and sows [43,68–71]. The sows during the last stage of gestation and the first three days of lactation (days 1 and 3) suffered from oxidative stress, as the serum levels of ROS and TBARS are higher than in

early gestation [69]. Our previous study reported that the use of PFA during the perinatal period has important antioxidative effects, improving reproductive parameters in sows and their litter characteristics under heat stress conditions [43].

Blood cells are also targets of oxidative stress due to the imbalance between the generation of ROS and the body's antioxidant defence mechanisms. This imbalance significantly contributes to the pathophysiology of these conditions, leading to RBC damage, and consequently, this oxidative damage ultimately leads to haemolysis, which is characterised by the loss of membrane integrity and the subsequent release of haemoglobin and other intracellular proteins [72]. Furthermore, oxidative stress can impair platelet function, promoting aggregation and thrombus formation [73]. It also impacts WBC counts, particularly neutrophils [74]. On the contrary, PFAs exhibit protective properties against RBC lysis, as demonstrated in vitro with human RBCs [75], along with anticoagulant effects [76]. Additionally, PFAs demonstrate immunomodulatory effects, countering cytotoxicity and apoptosis, while also exerting haemoprotective, immune-stimulatory, and anti-inflammatory effects [75,76].

This can result in haemolysis (destruction of RBCs) and anaemia. Additionally, oxidative stress can affect the bone marrow, where blood cells are produced, potentially leading to the decreased production of red blood cells, white blood cells, and platelets.

The objective of this study was to investigate the effects of a polyphenolic PFA on redox status, haematological parameters and piglet mortality in primiparous sows.

2. Results

2.1. Reproductive Parameters, Litter Characteristics and Body Conditions Indexes

Sixty-three (63) sows were included in the study. One sow of group T2 was withdrawn due to uterus prolapse on day 2 after the farrowing. Based on a thorough clinical examination and laboratory data, no association of the case of uterus prolapse with the administration of the additive was neither suspected nor identified. No other complications or adverse effects due to additive supplementation were recorded.

The performance parameters of the sows and litter characteristics results are presented in Table 1. Based on the comparative analysis, the mean number of stillborn piglets in group T1 (2.12) was significantly higher compared to group T2 (1.03) (p = 0.00, 95% CI: 0.52–1.66). Similarly, the mean number of alive piglets 24 h after farrowing and the mean number of the weaned piglets were significantly higher in group T2 (13.9 vs. 15.4 and 12.6 vs. 14.3, respectively).

Sows in group T2 presented significantly improved backfat at weaning (BFW) compared to group T1 (13.3 vs. 12.7, $p < 0.05$ 95% CI: 0.94–0.2). PFA supplementation had no significant effect on the BCS of sows at farrow and weaning (U = 404 p = 0.13 and U = 398 p = 0.124, respectively).

PFA supplementation did not affect the number of piglets that had to be fostered by other sows (p = 0.341). Similarly, the relative risk of fostering necessity in group T1 (1.4, 95% CI 0.8 to 2.5) presented with a nonsignificant difference compared with group T2 (0.7 95% CI 0.5 to 1.2) (p = 0.287). The additional mean number of crushed piglets in group T1 (1.31) was significantly higher compared to group T2 (0.38) (p = 0.00 95% CI: 0.54 to 1.31). Subsequently, the relative risk of crushing incidence in group T1 was 2.29 higher than that of group T2 (p = 0.00, 95% CI: 1.39 to 3.8) (Table 2).

2.2. Haematological Parameters

Regarding the haematological parameters, the mean value of PCV and the mean PLT count were significantly higher in the T2 group than those of the T1 group, while in the T2 group, the mean number of WBCs and Neu were enough higher than those of the T1 group, almost at a significant level (p = 0.051). The results are shown in Table 2.

Table 1. Results of the study parameters for litter characteristics and sows' performance [mean (standard deviation)].

Parameters	**Groups**			
Litter characteristics	**T1**	**T2**	**95% CI**	***p*-value**
Number of liveborn piglets	15.8 (2.4)	15.7 (1.7)	−0.9 to 1.2	0.800
Number of stillborn piglets	2.1 (1.3)	1.0 (0.9)	0.5 to 1.7	<0.001
Number of mummies	0.7 (0.8)	0.7 (0.6)	−0.3 to 0.4	0.809
Number of alive piglets 24 h after farrowing	13.9 (1.6)	15.4 (1.7)	−2.3 to −0.6	0.001
Number of crushed piglets	1.3 (0.9)	0.4 (0.6)	0.5 to 1.3	<0.001
Number of dead piglets until weaning	0.5 (0.6)	0.4 (0.6)	−0.2 to 0.4	0.730
Number of given piglets (fostering)	0.2 (0.5)	0.6 (0.7)	−0.7 to −0.1	0.009
Number of taken piglets (fostering)	0.7 (0.8)	0.2 (0.3)	0.1 to 0.8	<0.001
Number of weaned piglets	12.6 (0.9)	14.2 (0.7)	−2.0 to −1.1	<0.001
BW of piglets at weaning (kg)	7.5 (0.5)	7.7 (0.6)	−0.5 to 0.2	0.071
Sow performance	**T1**	**T2**	**95% CI**	***p*-value**
Back fat at farrowing (BFF) (cm)	17.3 (0.9)	16.9 (1.0)	−0.1 to 0.8	0.151
Back fat at weaning (BFW) (cm)	12.7 (0.8)	13.3 (0.7)	−0.9 to −0.2	0.030
Weaning to estrus period (days)	5.8 (0.8)	5.4 (0.6)	0.0 to 0.7	0.025

Table 2. Mean (Standard Deviation, SD), 95% CI and *p*-value for the Packed Cell Volume (PCV), White Blood Cell Count (WBC), Neutrophils (Neu), Lymphocytes (Lymph), Monocytes (Mono), Eosinophils (Eos) and Platelet Count (PLT) in peripheral blood of sows from the T1 group (control group) and T2 group (fed with supplementary PFA).

Parameter	**Group**	**Mean (SD)**	**95% CI**	***p*-Value**
PCV (% red blood cells in total blood volume)	T1	35.6 (3.7)	33.9–37.1	0.041
	T2	38.9 (5.9)	36.1–41.3	
WBC (cells/µL)	T1	11,110.0 (3072.8)	9935.3–12,428.5	0.051
	T2	13,261.2 (3667.9)	11,855.2–14,968.2	
Neu (cells/µL)	T1	6648.0 (1844.8)	5915.7–7504.0	0.051
	T2	7996.4 (2354.3)	7108.9–9051.2	
Lymph (cells/µL)	T1	3545.8 (1359.4)	3002.6–4101.5	0.224
	T2	4096.0 (1454.7)	3516.6–4806.3	
Mono (cells/µL)	T1	513.3 (329.3)	387.7–652.5	0.277
	T2	631.2 (347.0)	500.3–789.3	
Eos (cells/µL)	T1	403.0 (265.2)	288.4–522.7	0.104
	T2	537.8 (246.9)	440.7–658.6	
PLT (cells/µL)	T1	236,920.0 (112,964.8)	191,659.3–284,768.1	0.034
	T2	319,300.8 (123,236.2)	264,426.3–373,509.4	

2.3. Redox Biomarkers

The mean concentration of CARBS (nmol/mL) in group T1 (24.8) was significantly higher than that of group T2 (18.3). Similarly, the mean concentrations of TBARS (µmol/L) in group T1 (18.7) were significantly higher than in group T2 (14.9) (Table 3).

Table 3. Concentrations of CARBS and TBARS in sow plasma [mean (standard deviation)].

Mean Concentration	Group T1	Group T2	95% CI	*p*-Value
CARBS (nmol/mL)	24.8 (2.0)	18.3 (0.9)	5.1 to 7.7	<0.001
TBARS (μmol/L)	18.7 (1.2)	14.9 (0.7)	3 to 4.6	<0.001

3. Materials and Methods

3.1. Trial Farm

This study was carried out in August–September 2021 at a commercial farrow-to-finish pig farm in Central Greece (Thessaly) with 740 sows (hybrids of Large White × Landrace, DanBred, Ballerup, Denmark). All gilts/sows were ear-tagged individually and housed in a separate mating gestation building, where they were artificially inseminated (AI) with semen doses from Duroc boars. The farm maintained a grandparent nucleus of sows for producing its gilts. Previous examinations for the genotyping of Porcine Stress Syndrome (PSS) in grandparent sows using polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) revealed the presence of ryanodine receptor gene (ryr1) in the grandparent nucleus [77]. They also showed increased aggressive and inappropriate maternal behaviour.

One week before the predicted day of the farrowing, the gestating sows were moved from the mating gestation building to the farrowing building (16 sows per group/farrowing room). The facilities of each farrowing room included 16 pens with farrowing crates, which were equipped with nipple drinkers and feeders for the sows and the piglets. No enrichment material (e.g., straw) was used in farrowing pens. On the day of the weaning, sows were moved to the mating–gestation building and were housed in individual cages with slatted floors and separate feeding stalls until the AI (weaning to oestrus interval). The inseminated sows remained in individual cages until 30–35 days of their gestation, and then they were moved to group housing facilities until one week before the predicted day of the farrowing. Piglets were weaned at about 28 days of age and were moved weekly into the flat deck unit, where they were grouped in pens of 25 pigs.

The home-mixed diet of sows during gestation and lactation is presented in Table 1. The feeding schedule of primiparous sows since the 80th day of gestation and during lactation is presented also in Table 4. During the lactation period, on the days that the feed amount was up to 6 kg, this was provided in 2 meals per day. The diet of suckling piglets, except their mothers' milk, included a milk replacer for the first 7 days of age and a part of commercial creep feed until the weaning day.

Each farrowing room included pens with farrowing crates, including separate removable feeders for the sows and the piglets. The drinking water was provided automatically, and the flow of the nipples was checked every day by an animal technician. Monitoring chemical and microbiological checks were applied every month to the routine program. Housing facilities were equipped with a fully automated feeding system for the weaners and a climate control system for temperature and humidity for the farrowing and the weaning house. The farrowing rooms were maintained at ambient temperature (23 ± 0.5 °C) with lights on/off at 07:00/21:00, and natural light was provided by windows in each room. An infrared heat lamp was suspended in the centre of the floor area on one side of the farrowing crate over an insulated rubber mat (the average temperature under the heat lamp during the study period was approximately 30–35 °C). All piglets were kept in farrowing pens under the same conditions. Weaned piglets were reared under similar feeding and environmental conditions (climate, ventilation, temperature, and air humidity), using a fully automated feeding/drinking system and a climate control system.

Table 4. Feeding schedule, diet composition and nutrient content of gestation feed (GF) and lactation feed (LF) of sows' diet.

Feeding Schedule		
Stage	**Amount of feed (kg)**	
80th–110th day	1.5 (GF)	
110th–one day before farrowing	1.5 (GF)	
day of the farrowing	0.5 (LF)	
1st day after farrowing	1.0 (LF)	
2nd to 10th of lactation	increase of 0.5 per day (LF)	
10th–12th day of lactation	maximum: 2.0 + 0.4 per piglet (LF)	
13th–22nd day of lactation	8.0 (LF)	
23rd–24th day of lactation	4.0 (LF)	
Day of weaning	2.0 (LF)	
Composition of ingredients (kg)	**GF**	**LF**
Corn	0.300	344
Barley	0.280	200
Wheat bran	0.235	200
Soybean meal (46% crude protein)	0.120	170
Soybean oil	0.010	20
Protein concentrate (68% crude protein) *	0.013	24
Vitamins/minerals premix **	0.030	30
Inactive dried yeast ***	0.005	5
Mycotoxin binder ****	0.002	2
Dietary cellulose powder *****	0.005	5
Total	1	1
Analysed nutrient compositions (%)	**GF**	**LF**
Crude protein	16.50	18.40
Crude fat	3.70	4.65
Crude fibre	5.40	4.80
Lysine	0.80	0.96
Methionine	0.29	0.33
Methionine + Cystine	0.60	0.63
Calcium	0.65	0.86
Total phosphorus/available phosphorus	0.76/0.40	0.78/0.46
Sodium	0.24	0.24

* Apsaprotein F68 (Andres Pintaluba SA, Reus, Spain). ** The source and composition of the vitamin and mineral premix are analytically presented in Supplementary File S1. *** Prosol Expert (Prosol SPA, Madone BG, Italy). **** Apsa Quimitox Plus (Andres Pintaluba SA, Reus, Spain; bentonites, sepiolite clay, dried yeast-*Sacharomyces cerevisiae*, purified diatomaceous earth). ***** Arbocel® (J. Rettenmaier and Söhne GmbH, Rosenberg, Germany).

The routine vaccination program of sows included vaccinations against Aujeszky's disease, erysipelas, parvovirus, atrophic rhinitis, porcine reproductive and respiratory syndrome, porcine circovirus, swine influenza, colibacillosis and *Clostridia*. For antiparasitic control sows, a single ivermectin injection was applied 14 days before farrowing.

3.2. Experimental Material

A commercial phenolic PFA (Herb-All^{M} CALM, Life Circle Nutrition, Wangen, Switzerland) was tested. Herb-All^{TM} CALM is composed of pure herbal compounds from *Embelia officinalis*, *Ocimum sanctum*, and nut fibre with a specific high natural content of polyphenols (>6.0%). The commercial PFA contains eight mainly polyphenols (gallic, syringic, benzoic, p-coumaric and vanillic acids as well as catechin, kaempferol and naringenin) and other secondary plant metabolites such as flavonoids, tannins, saponins, alkaloids, steroids, terpenoids, glycosides and reducing sugars.

According to the manufacturer, this commercial PFA, due to its synthesis, can improve the natural levels of serotonin and reduce stress-related corticosteroids. It can also calm down agitated or aggressive animals and thus reduce mortality in early phases. This prod-

uct was administrated with top-dressing at a dose of 10 g/day per sow for 14 days before farrowing until the 7th day of lactation, according to the manufacturer's recommendations.

3.3. Study Design

Sixty-four (64) primiparous sows (mean age of 366 ± 3 days) of a single batch were selected 15 days before the expected farrowing date according to no previous health history and similar body weight (206.8 ± 5.7 kg). The criteria for selected primiparous sows were their strong defensive reaction, (e.g., sow stands up, is nervous and aggressive) to the "Towel Test" according to Neu et al. (2021) [78]. The aggressive behaviour of selected primiparous sows was tested using the following "Towel Test" for the estimation of their reaction to unknown objects and situations by a towel being suddenly thrown in the direction of the sow's head during a resting period [78]. No significant differences in mean body weight between selected primiparous sows were noticed during the period 7 days before farrowing (213.8 ± 8.4 kg) until the day of the farrowing (220.5 ± 10.2 kg).

All primiparous sows received a single injection of D-cloprostenol (1 mL per animal, equivalent to 75 μg of D-cloprostenol per animal/Gestavet Prost®, Hipra, Amer, Girona, Spain) at 14.00–16.00 on gestation day 114. Sows that had not farrowed by 05:30 the following day received 10 IU oxytocin. The above scheme was performed to ensure the same farrowing day for all sows of the trial in order to increase the likelihood of piglet delivery during working hours as well as to allow a closer management of the trial.

Based on previous similar research [39], for sample size calculation, a confidence interval of 95% with 80% power and a relatively high standardised difference between two means (Cohen's d = 0.75) were selected, which yielded a number of 58 plus 10% for potential withdraws to a final number of 64 animals. Allocation of the participated animal was randomly conducted using a number generator (True Random Number Service https://www.random.org) (accessed on 21 January 2024)to one of two groups, as shown in Figure 1:

(a) T1 group-control group (32 sows): regular gestation (GF) and lactation feed (LF);
(b) T2 group (32 sows): regular GF and LF supplemented with top-dressing of the commercial PFA product (Herb-All™ CALM) (10 g/day in the morning meals per sow) for 14 days before farrowing until the 7th day of lactation, according to the manufacturer's recommendations.

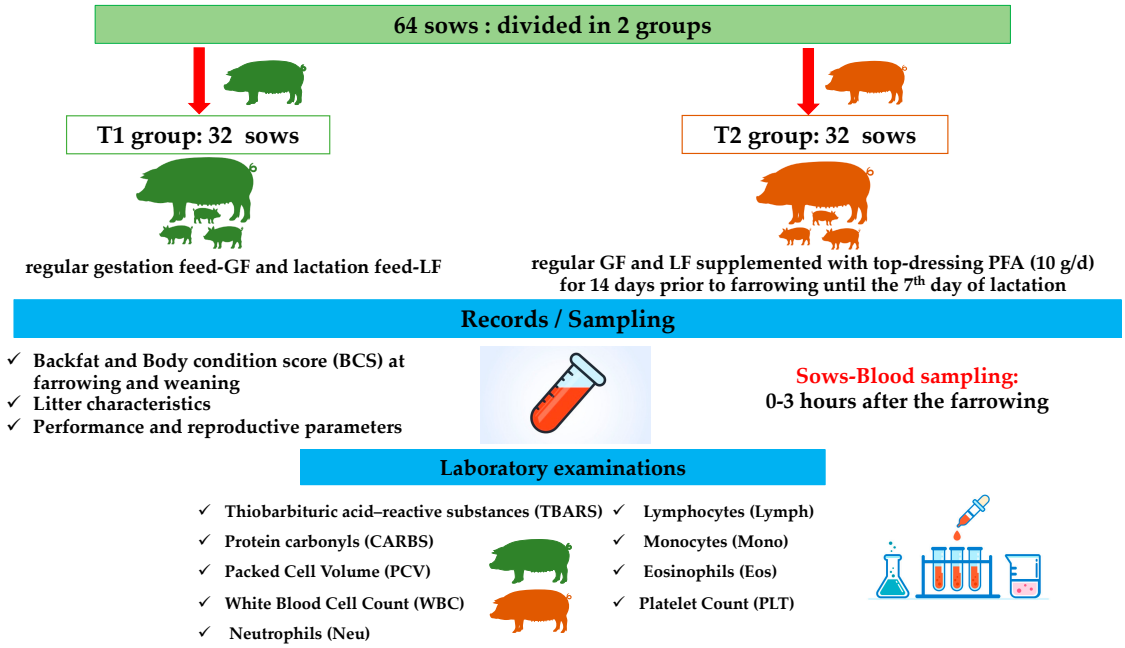

Figure 1. An overview of study design (records, sampling, and laboratory examinations).

The sample size for the determination of a significant difference in the concentration of TBARS and CARB between the two groups was based on a standardised difference between two means (Cohen's d = 1.6), and a confidence interval of 95% with 80% power according to the previous findings of Papatsiros et al. [43]. Therefore, a total of 40 samples were suggested to be obtained (20 samples from each group). This calculation was applied to obtain the necessary samples capable of providing robust results most economically.

The field researchers and handlers (two and two) in the present study were blinded to the allocation and intervention of animals.

3.4. Blood Sampling

Blood samples were collected via jugular venipuncture from 20 sows per group restrained by snout snare during the first 0–3 h after the farrowing, using a vacuum tube containing ethylenediaminetetraacetic acid (EDTA) (Venoject; Terumo Europe, Leuven, Belgium), S-Monovette® 9 mL, lithium–heparin (Sarstedt AG & Co. KG, Nümbrecht, Germany) and disposable 14Gx3-1/414, 2.1 × 80 mm needles (Frisenette ApS, Knebel, Denmark). The packed cell volume (PCV) was assessed through the microhematocrit method, as outlined by Bull et al. [79]. PCV measurement involved determining the height of the red cell column in the centrifuged tube. Additionally, blood smears were created from each sample, which was followed by drying and staining with Giemsa. The number of WBCs and the number of PLTs were counted in blood smears (Harvey). Furthermore, a differential number of WBCs was calculated. Plasma samples were obtained by centrifugation (5810 R, Eppendorf AG, Hamburg, Germany) at 3000× *g* for 15 min, at 4 °C; then, the supernatant was transferred into 1.5 mL microcentrifuge tubes and stored at −80 °C pending laboratory analysis.

3.5. Laboratory Examinations for Redox Biomarkers

The redox biomarkers TBARS and CARBS were evaluated in plasma based on the approach of Gerasopoulos et al. [80,81]. A modified assay of Keles et al. [82] was used for TBARS (μmol/L) determination. TBARS concentration was calculated based on the molar extinction coefficient of malondialdehyde (MDA). CARBS (nmol/mL) determination was performed according to Patsoukis et al. [62] and was based on the molar extinction coefficient of 2,4-dinitrophenylhydrazine (DNPH).

3.6. Records

The sows' body condition (BCS) was measured visually and using backfat (BF) measurements on farrowing (BFF) and weaning day (BFW) (about 28 days after farrowing). The researcher conducted the previous scores and was blinded to the allocation of the animals, assessing the visual measurement, using a scoring system of score 1 (for extremely thin sows) to 5 (for extremely fat sows) [63]. Backfat measurements were performed by the same person in the back area at point P2 of the rib, 6–7 cm lateral to the dorsal midline, using a pulsed ultrasound (Lean-Meater® Series 12, Renco Corporation, Manchester, MA, USA). The point of measurement was marked on each examined sow to guarantee that the same spot was assessed during the subsequent measurements.

Moreover, litter characteristics (mean number of total liveborn, stillborn, mummies, alive piglets 24 h after farrowing, crushed during the first 5 days after farrowing and weaned piglets), as well as the weaning to oestrus interval in days, were recorded. Stillborn piglets were defined as piglets that died before the expulsion without any sign of decay [83].

3.7. Statistical Analyses

All data were collected in an Excel data sheet (Microsoft Excel). Comparisons of the mean differences between the two groups were conducted by applying the two-tailed independent Student's *t*-tests. Differences in the frequency distribution of ordinal data, such as BCS at farrowing, and BCS at weaning, were evaluated by the Mann–Whitney U test. The relative risk analysis for crushing events and fostering necessity was conducted

by Chi-squared test. The differences in the haematological parameters were evaluated by the t-test. The level of statistical significance was set at 0.05, and statistical analysis was conducted in SPSS IBM (version 20). The level of statistical significance was set at 0.05, and statistical analysis was conducted in SPSS IBM (version 20).

4. Discussion

The composition of the tested PFA was based on plant extracts such as Embelia officinalis, Ocimum sanctum and nut fibre. The antimicrobial, antioxidant and growth-promoting effects of all these ingredients have already been reported. In particular, Bhattacharya et al. (2000) [54] mentioned that the herb Embelia officinalis has shown a protective effect against a variety of pathogens, including bacteria, fungi and parasites. In addition, it has antioxidant properties due to its ability to scavenge free radicals and reduce oxidative stress [54,55]. Several studies have demonstrated the antibacterial, antiviral and antifungal effects of Ocimum sanctum against a range of pathogens [57]. It is also rich in antioxidants such as flavonoids and phenolic compounds that help neutralise free radicals and reduce oxidative stress [56,57]. Nut fibres contain various fatty acids that have an antimicrobial effect against bacteria and fungi [59]. They also contain antioxidants such as vitamin E, polyphenols and flavonoids, which help to reduce oxidative stress [58,60]. Consequently, they could all indirectly contribute to the growth of pigs due to their antimicrobial and antioxidant effects, which in turn could promote immune function. In addition, these herbs contain compounds that give them antithrombotic, anti-inflammatory and protective effects on blood cells [55,57,59,60].

In this study, the mean value of PCV was significantly higher in the group where sows were fed with PFAs. More specifically, our results are consistent with a study in rats where the group that was fed with *Ocimum sanctum* had a significantly higher mean number of RBC and PCV in short and long-term durations [84]. Additionally, the effect of *Emblica officinalis* in RBCs could have a cooperative action in the increase in them, and consequently in the increase in PCV, as it seems to have a protective role in RBCs, leading to a dose-dependent increase in their number [85]. In a study where PFAs were fed to broiler chickens, there was only a slight increase in RBCs number [86]. On the other hand, there was no difference in the mean values of PCV in buffalo calves fed with PFAs [87] as well as in poultry [88]. The higher mean number of WBCs in the group that was fed with PFAs was concerning, with almost a significant difference from the control group, which seems to be due to the higher number of Neu in our study. A significant increase in their number was observed in broiler chickens as well [86], while in another study in poultry, there were observed no difference in the mean counts of WBCs [88]. In the previously mentioned experiment in rats fed with leaves of *Ocimum sanctum*, there was a significant increase in the number of WBCs in short-term durations, which is contrary to the long-term durations where there was a significant decrease. Here, the attributed effects may stem from the haemoprotective, immune-stimulatory, and anti-inflammatory properties along with the antioxidant capabilities of *Ocimum sanctum* [84]. Lastly, the highest mean number of PLTs in the T2 group might be due to the anticoagulant effect that *Ocimum sanctum* fixed oil has, as has been reported by Singh et al. [89], where the oil seemed to have an antiaggregatory action on platelets.

In our study, the administration of PFAs in the diet of sows during the perinatal period resulted in a significant reduction in redox biomarkers (TBARS, CARBS) as well as a significantly higher mean number of alive piglets 24 h after farrowing as well as weaned piglets. Previous studies, using PFA in sows' diets during gestation and lactation, indicated an enhanced antioxidant status in sows [43–46,90,91]. PFAs are based on plants that are rich in antioxidants, and among them, polyphenol is the most common substance [2,46]. Plant-derived polyphenols have beneficial effects for gestating and lactating sows, as they can beneficially regulate the placenta and mammary glands of sows, thus resulting in better growth, development, and physiological functions of offspring piglets [47]. The tested commercial PFA in our study contains 60% pure herbal compounds with a specific high

natural content of polyphenols (>6.0%), which may explain its high antioxidant properties in sows. In particular, the tested commercial PFA is based on plant extracts (*Embelia officinalis*, *Ocimum sanctum*, nut fibre) with high antioxidant activity to reduce oxidative stress that was reported in vitro studies or trials in rats or humans [54–60]. The novelty of our study was the investigation of the effects of the above plant extracts on the redox status of sows and piglet mortality under field conditions. However, more research is needed to better understand their antioxidative properties and impact on animal health.

In our study, the tested commercial PFA has beneficial effects on the reduction in the mean number of stillborn, alive piglets 24 h after farrowing and crushed piglets and consequently on the mean number of weaned piglets. Piglet mortality and especially the increased number of stillborn and crushed piglets is an important welfare issue for modern sows. Chronic stress has a detrimental effect on sow welfare and productivity, as well as on the welfare and resilience of their piglets, which is mediated prenatally [20]. Crushing usually occurs during the first 3 days after birth with around half occurring during the first 24 h when the sow changes posture [92]. In commercial individual farrowing crates, the piglets' survival may be put at risk due to the crushing incidences from sow postural changes [93,94]. Nowadays, crushing is an important welfare issue for modern hyper-prolific sows, and it is the result of a complex interaction between sow and piglet behaviour [95–97]. Moreover, sows coming from group housing in the gestation stage and moving to confinement in an individual farrowing crate immediately before parturition may be stressed with negative consequences for their productivity (e.g., by increasing the number of stillborn piglets) [98,99]. Based on our study's results, the administration of a polyphenolic PFA in sows during the perinatal period could improve their welfare and performance and, consequently, the economic balance in pig production through the improvement of production parameters.

Piglet perinatal and pre-weaning mortality is an important economic concern in pig production, causing serious losses between €12 and 23 per litter [21–23,100]. It is one of the key factors that produce piglets weaned per sow per year, which is used as an integrated measurement of reproductive performance in sow herds [26,101,102]. Furthermore, piglet perinatal and pre-weaning mortality may involve pain and/or suffering, which is considered a welfare issue [22,23,29,31–33]. Therefore, the use of PFA in sows during the perinatal period could have an important economic impact on pig production, leading to a reduction in losses due to piglet perinatal and pre-weaning mortality.

Previous studies reported the beneficial effects of PFA on the milk characteristics and reproduction performance of sows [1] as well as their performance regarding the improvement of the backfat index at weaning [43]. A limitation of our trial is that no measurements of milk production were performed in experimental sows. However, we observed that the administration of PFA in sows' diet during the perinatal period has a beneficial effect on BFW and the weaning to oestrus interval. The sow's body size and shape are important as a predictor factor for the incidence of intrapartum stillborn piglets in farrowing sows [103]. Moreover, the over-conditioned sows have also been found to be at risk of prolonged farrowing that is accompanied by an increased number of stillborn piglets [104].

Minimising the oxidative stress of pigs in intensive production systems is essential for optimising health and productivity, which contributes to achieving pork production goals through One Health and environmental sustainability [105]. A more holistic approach should be considered in herd health management of modern high-profiling sows, using PFAs with antioxidant properties in the swine industry in a routine program. The performance of high-profiling sows is directly related to the productivity of modern pig farms, as when they are affected by oxidative stress during the perinatal period, their performance parameters and the growth of their piglets are affected [2]. The implementation of nutritional strategies to alleviate oxidative stress in high-profiling sows is crucial for their performance parameters during the gestation and lactation periods [2]. Reducing sow stress during lactation improves sow and piglet performance and welfare [106]. Based on our study's

results, using PFA in sows during the perinatal period could improve the welfare and performance in sows. The beneficial effects are due to their antioxidative properties that are correlated with an improvement of litter characteristics and piglet mortality (decreased stillborn and crushed piglets, increased weaned piglets per litter) as well performance parameters and better input of weaning sows due to their BFW and weaning to oestrus interval index.

5. Conclusions

In the present study, the administration of a polyphenolic PFA in farrowing sows during the perinatal period has beneficial effects on their welfare and performance. The use of PFA due to their antioxidative potential has beneficial effects on several parameters such as a decreased number of stillborn and crushed piglets, increased number of weaned piglets per litter as well better input of weaning sows due to their improved backfat index and weaning to oestrus interval. In addition, PFA's use seems to have an impact on the value of PCV and the number of PLTs, WBCs and neutrophils. However, future studies are needed to address further the role and mechanisms of antioxidative properties of PFA in improving the performance and welfare parameters of sows during the perinatal period.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/stresses4020018/s1, Supplementary File S1: Premix of vitamins/minerals.

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