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Abstract

Claw lameness can be associated with biomechanical factors caused by imbalances of the pressure distribution under the hooves when swine are confined in modern facilities with hard concrete flooring. Comparing hoof pressure distribution data of swine boars walking over two different types of floors (standard concrete vs. 3mm rubber mattress) in previous research, it was found a great advantage favoring the rubber mat flooring showing that it was capable of reducing pressures under the claws as the pressure became more evenly distributed under this treatment resulting in balanced weight-bearing surfaces. The objective of this study was to develop an expert system based on Fuzzy logic algorithm for the prevention of hoof pathologies applied to the intensive swine production by estimating occurrence of claw lesions based on the association of knowledge gathered on pressure distribution from previous research as well as the influences of nutrition, friction coefficients found on different types of available flooring, hoof sizes and animal weight on the welfare of the swine's locomotory system. The data were correlated initially using Matlab® platform associating expert's knowledge and literature through a knowledge system that weights the variables according to their impact on claw health. The final user interface was coded using Microsoft Visual Studio Rapid Application Development tool and the resulting system was validated in several different laboratory scenarios and its performance was considered to be satisfactory according to findings in the literature. The expert system was coded and the authors concluded that the system could be a great contribution and advance in the swine's industry, nonetheless, its performance still requires field testing for fine adjustments which should be encouraged to be carried out in further researches.

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1. INTRODUCTION

The Fuzzy logic theory was introduced, in 1962 and 1965, by Lotfali Askar-Zadeh, professor of the Department of Electrical engineering of the University of California - Berkley-USA, with the intuit of giving mathematical treatment to certain subjective linguistic terms such as, "approximately", "around of" among others ([28]; [29]; [30] and [31]).

According to ref. [1], to overcome the fuzziness and uncertainty problem, expert systems based on fuzzy

logic can be considered.

A natural question is the effectiveness of the use of Fuzzy Logic for health-status certification in Preventive Diagnostics, and to develop an Expert's System aiming the reduction of losses in order to maintain economically feasible the processes involved. The answer has two aspects: first, the aspect that Fuzzy Logic is well suited for controlling/predicting a process or system that is nonlinear or poorly understood to use conventional control designs, and second is that it enables control engineers to systematically implement control and monitoring strategies used by human operators with experience and expertise.

According to [29] and [30] in contrast to crisp set, a Fuzzy Set is a set without a crisp boundary. This means the transition from "belong to" set and "not belong to" set is gradual. This smooth transition is characterized by membership functions that give flexibility in modeling linguistic expressions.

Fuzzy Inference is the process of mapping from a given input to an output using Fuzzy Logic. The mapping then provides a basis from which decisions can be made or patterns discerned.

The process of Fuzzy Inference involves all of the concept's membership functions if-then rules and Fuzzy operators. The essential components of a Fuzzy System are the Fuzzy Inference engine, Fuzzy rule base, and defuzzifier. The following definitions explain the blocks used in the Fuzzy System.

Since the inputs in most applications are real numbers, the fuzzifier serves as the proper interface between the Fuzzy Inference engine and the physical world. The criteria, according to [29] and [30] in designing a fuzzifier are:

1. The Fuzzy set A should have a large membership value at x.
2. The fuzzifier should simplify the computations involved in the Fuzzy Inference engine.

Fuzzy Inference, as presented in the research of the ref. [17], is a method that interprets the values in the input vector and, based on user-defined rules, assigns values to the output vector. The Fuzzy Logic Toolbox provides a set of editors that let you build a Fuzzy Inference System (FIS).

In a Fuzzy Inference Engine, Fuzzy Logic principles are used to combine the Fuzzy IF-THEN rules in the Fuzzy rule base into a mapping from a Fuzzy set in an n-dimensional universe of discourse to a Fuzzy set in a one-dimensional universe of discourse [29] and [30].

The inference method introduced by MAMDANI [15], as also presented by the ref. [17], proposed an inference model that was used in this research to design the Fuzzy Controller. The Mamdani Fuzzy Inference System employs the individual rule-based inference scheme and derives the output y when subjected to a crisp input x.

The Fuzzy Set Theory (FST) introduces a tool that can be efficient for monitoring and preventing a variety of pathologies in the medical and veterinary fields since these areas are often surrounded by vagueness and subjectivity due to the nature of the medical field to be dependent on several sources of uncertainty [29].

As suggested in the ref. [26], as some of the sources that represent fuzziness to be, for instance, lack of information, non-specificity, probabilistic nature of data and outcome, vagueness in the formulation of recommendations, conflicts among various sets of alternatives, and fuzziness in the determination of clinical signs. In his work, he discusses the application of FST theory in dealing with sources of fuzziness of textual clinical guidelines in formulating automated alerts and advice for a CPOL (Care Plan On-Line), an intranet-based chronic care planning system intended for general practitioners (GP). The client-side of

the CPOL is a relatively generic shell that receives guidelines and EMR (Emergency Room) specifics from a central server.

Other examples of the use of Fuzzy Logic are in the detection of signs either for optimization of the reproductive protocol of farms and in the effects of heat stress-related production losses, which are areas that have been proven to be benefited economically by correct monitoring of behavior patterns. Some of the work done for monitoring animal heat stress related to production losses was described by the references [2] and [9] for mastitis and oestrus detection in dairy cattle.

This research aimed to estimate the occurrence of lameness in-housed male pigs in concrete pens using Fuzzy Logic. This paper describes the algorithm and the resulting system was tested in several different laboratory scenarios.

2. MATERIAL AND METHODS

The preliminary knowledge base was created gathering information that related pig claw pressure distribution over two types of flooring system (standard concrete vs. 3mm rubber mattress) [4].

The rule base was initially elaborated using a Microsoft Excel Spreadsheet to correlate all the variables composing the system and to apply the weights to each variable according to its importance in predisposing claw lameness, discussed later in this chapter.

The variables were selected according to its influence on hoof pathologies previously described through literature and experimentation.

The variables biotin (representing nutrition) The B vitamin, biotin (Vitamin H), is an essential coenzyme that takes part in biological carboxylation reactions. It is involved in the tricarboxylic acid cycle, gluconeogenesis, and fat synthesis. Biotin is a factor in controlling the rate of production and deposition of proteins such as keratin, which is a component of skin, hair, and horn.

Biotin is an essential coenzyme in carbohydrate, fat and protein metabolism [16]. Dietary supplementation of biotin has been shown to increase the claw pig strength and reduce digital lesions in pigs) and floor roughness has been studied and is well documented as far as provoking claw lesions in modern swine farming [7]; [18]; [3]; [27] and [13]. On the other hand, the association among animal weight, claw area and the use of alternative flooring such as rubber mattress were obtained through experiments performed as part of this research project. The results obtained for these variables were correlated to biotin and floor roughness to build the algorithm presented here.

The combination of nutritional factors, such as biotin, floor roughness, weight influence, interacting or not with plantar surface pressure (given by the claw natural physiological growth) was used for implementing the rule governing the Fuzzy logic controller.

The Fuzzy logic controller was created using the software Matlab[®] Fuzzy toolbox based on 540 rules organized initially using Microsoft excel spreadsheet and implemented in the Matlab[®] interface associating 5 input variables: Mat thickness in millimeters (mm), according to ref. [4], Animal weight (kg), claw area (mm²), Friction coefficient (unitless), according to ref. [7] and biotin supplementation (µg/kg) as stated by ref. [19]; [3]; [27] and [13].

The system outputs a value corresponding to the risk of developing claw lesions (APL). It is composed of

7 linguistics terms: very low, low, medium, high, very high, extremely high.

The input variables were composed of either Gaussian or Trapezoid pertinence functions applied to the Mamdani inference method [15].

Mamdani's method is the most commonly used in applications, due to its simple structure of 'min-max' operations. To exemplify the construction of membership functions, the friction coefficient pertinence function was chosen and is presented in Figure 1.

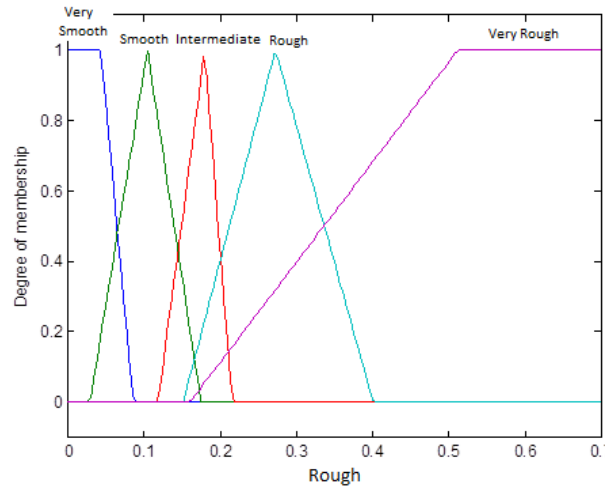


Figure 1. Pertinence function for the friction coefficient variable.

The graphic representation of the Fuzzy system is initially designed using the Matlab® toolbox for the simulation of the preventive diagnostic system and further develop the final version of the expert system. The objective of the rules is to either filter or add information into the possible scenarios using the input variables associated to each other to output a value indicating the risk associated with the possible onset of claw condition according to the information provided by a user.

For the linguistic variable “Friction coefficient”, it was considered an interval of [0, 0.7] unitless, where 0 is a low friction coefficient and therefore slippery in contrast to 0.7, a high friction coefficient and therefore very abrasive. Both extremes are not desirable and therefore have been given high values for weight in the system.

Both trapezoid and triangular pertinence functions were used to represent this variable as they were found to best describe the flooring coefficient intervals according to literature cited previously.

The coefficients were classified as Very Smooth (ML), Smooth (L), Intermediate (I), Rough (A) and Very rough (MA) with the following intervals respectively: ML [-0.0504 -0.0056 0.0441 0.0861], L [0.02968 0.105 0.175], I [0.119 0.18 0.216], A [0.152 0.273 0.401] e MA [0.161 0.512 0.715 0.831].

For the linguistic variable “mat thickness -Ep”, was considered an interval of [0, 3], representing the length in millimeters (mm). With an interval of [-1.0 0 0.75] and Gaussian pertinence function representing the limits of a floor thickness of 0mm or simply concrete, [0.25 1 1.75] triangular pertinence function representing the limits of an alternative floor thickness of 1mm or thin mattress with low protection, [1.25 2 2.75] triangular pertinence function representing the limits of an alternative floor thickness of 2mm or slightly thick mattress with medium protection and [2.25 3 5] triangular pertinence function representing the limits of an alternative floor thickness of 3mm or thick mattress providing the best protection tested.

Considering nutritional factors as biotin levels added to ration, where lack of suitable levels is proved to affect claw integrity and health by making the claw soft and fragile to stresses and predisposing to increasing incidence of lesions ([27] and [13]), other factors as: animal weight, sole area and friction coefficient of flooring used in pens are sufficient to provoke abrasive scars and further lesions of the soft tissue of claws by exposing vital fragile structures to inadequate pressures [7].

Therefore, there is a great benefit by providing pavement with certain amount of cushioning that will influence the pressure distribution and therefore improving balance to these pressures under the claws as well as reducing friction coefficient to healthy levels which consists of enough abrasion only to stimulate horn growth and avoid slips and not damaging it or causing fractures by slipping and falling.

For these reason and severity of scenarios created through association among the five input variables, the results of the association of mechanical factors and nutritional factors can elevate the possibility of developing lesions on heavy boar claws with proved genetic performance as well as reducing them if the conditions of the input variable are changed by the user by providing better management conditions.

For the linguistic variable "Biotin -Bio", was considered an interval of [0, 1560], in ug/kg, with an interval of [0 0 185 401.1] and trapezoid pertinence function representing minimal levels of biotin supplementation, [218 399 700 859.5] light and [671 955.5 1560 1570] ideal supplementation.

The variables: Animal weight – (Pan) and Claw area – (Aan), follow the same method with intervals obtained from results of experiments using the Matscan – DB - Tekscan[®] pressure distribution system – Boston, MA - USA [6].

The addition of weights to the variables interacts by either increasing or reducing the severity of scenarios and was designed using a pattern obtained from knowledge gathered from literature ([19]; [3]; [27] [13] and [7]) and experimentation in this project.

Each item of a variable counts with a value given according to its importance and impact on health in relation to the others which will contribute to aggravate or attenuate the final ALP in a given situation. When associated with the algorithm will sum and produce a numerical result that is translated in the linguistic output (ALP) variable with a range that represents several prognosis conditions for the farm management.

The form the weights were applied to the variables was by adding values to each factor of a variable (i.e., 5, 10, 15). When the factors of a variable are associated, the sum of the weights of the factors being associated yield the final output risk which ranges from 0 to 100.

In a hypothetical situation, i.e., concrete would have a high weight value of 15 (for concrete flooring represent a high-risk level it will be given a high value).

A high level of biotin in a diet (i.e., 800 ug/kg), represents a low-risk level having a positive effect on claw health as opposed to concrete and therefore will be given a low weight value of 2 and so on. Adding mattress to the floor will reduce the variable's factor weight value proportionally to its thickness. The thicker the lower the factor's value and therefore the system's output value that will represent the risk associated.

The method of summing numerical values for the independent factor within a variable was adapted from a known system consensually used worldwide in the medical field for the subjective emergency evaluation of the neurological state of a person following a polytrauma. Glasgow Coma Score evaluates levels of consciousness and neurological reflexes of a patient attributing values to the presence or absence of vital

signs leading or not to the need for a specific emergency intervention [10].

3. RESULTS AND DISCUSSION

The results of the Fuzzy inference system can be tested by changing the values of the input variables on the Matlab[®] rules interface and checking the resulting changes on the corresponding surface chart generated by the Matlab[®] software. The lesion development possibility (ALP) displayed in Figure 2 is as a nonlinear function representing the level of biotin supplement given as a function of the thickness of the mattress.

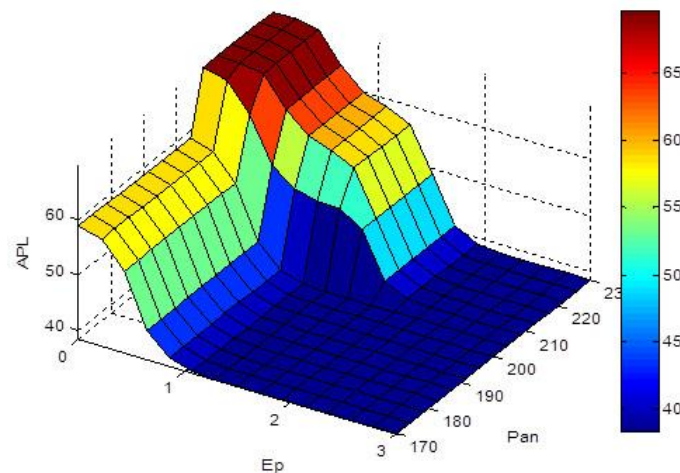


Figure 2: Surface chart of possible scenarios using mat thickness and biotin as input variables.

The chart in question provides a general representation of the system and also permits adjustments for eventual errors in the set of rules assembled previously by correlating the expert information gathered into the system's database. The surface chart allows the visualization of the points represented by associating the variables that fall out of the performance.

The decision support system is achieved by controlling levels of nutritional components, mostly by increasing levels of biotin, altering floor properties with better-cushioning properties and dissipating better stresses and adequate roughness to increasing lifespan of claw soft tissue structures, also preventing fractures by falling due to slippery floors.

The software can give a range of alternatives to accommodate the farm's profile according to its managements and will analyze the risks of several choices by farmers and farm managers.

The system's algorithm was tested in Matlab[®] Fuzzy logic ToolBox using various distinct scenarios associating adequate, inappropriate and deficient levels of biotin as nutritional variables to the 3 different thicknesses available for mattresses tested in the field, as well as combinations of flooring roughness, animal weight and claw area obtained during field experiments.

There were performed 40 simulated situations at random for suitable range of outcomes from minimal probabilities such as ALP of 8,85% using high amount of biotin (1000 ug/kg), 3mm rubber mat, 0,25 for coefficient of friction for the mat, and an animal of approximately 200 kg in weight to severely probable (ALP of 91,8%) using low amount of biotin (200 ug/kg), 0mm or concrete flooring, 0,40 coefficient of friction for concrete, and an animal of approximately 220 kg in weight (Tables 1).

Table 1. Extreme situations obtained by the scenario’s combinations.

scenario	ET (mm)	Pan (kg)	Aan (cm2)	Roug (unitless)	bio (ug/kg)	ALP (%)
better	3	200	45	0.25	1000	8,85
worse	0	220	20	0.40	200	91,8
intermediate	0	190	35	0.45	400	58,9

A correlation between Claw area (Aan), Biotin (bio) and Mattress thickness can be seen in Figure 3.

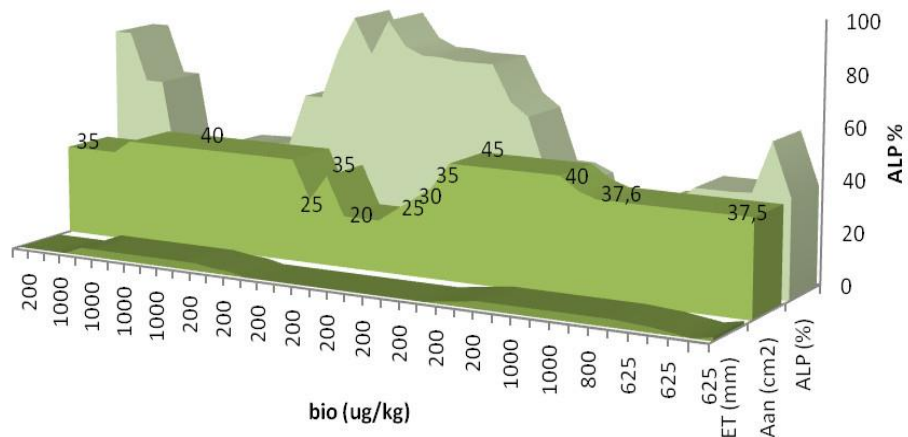


Figure 3. Correlation between Claw area (Aan), Biotin (bio) and Mattress thickness

The prognosis software was developed using a Microsoft® tool called RAD (Rapid Application Development). The application is called Microsoft Visual Studio. System developed for building 32/64 Bits application for Windows® operational environment.

In this application was coded the algorithm tested with Matlab® tools and designed all the input and output interfaces of the expert system. It was developed a set of input/output data interfaces as well as assembling and edition of the support tool for the decision system.

These interfaces were designed in a way to allow a suitable dialog between the end-user and the system including veterinarians, framers, Farmworkers and technicians, livestock facility designers, feeding industry personnel, among others.

The use of the Matlab® mathematical tool with its Fuzzy logic toolbox provided a set of editing possibilities to build the Fuzzy inference system (FIS) and allowed the validation through laboratory testing of the mathematical core algorithm helping to estimate hoof pathologies based on the independent input variables enlaced to the projected dependent variable.

Figures 4, 5 and 6 correspond to some of the functional steps of the designed software running using a microcomputer working under Windows® operational system.

After the installation of the system, a splash screen is loaded, following its operational interface and independent variables data input (Figure 4 and 5).

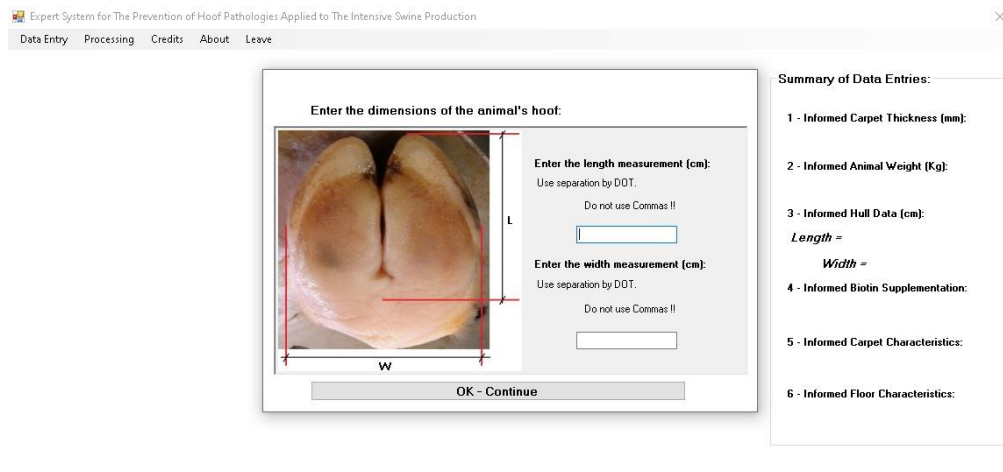


Figure 4. Data input for calculation of the approximated claw area

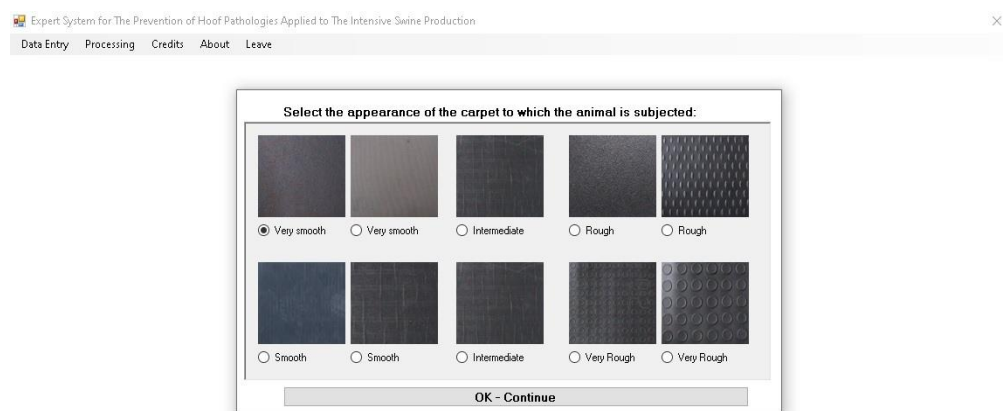


Figure 5. Data input for alternative stall flooring.

The information input by the user are regarding the facilities through the type of flooring, biotin levels, claw area which is estimated by the herd’s mean claw length and width and the area is calculated by the software.

After the data input, the system will calculate the possibility of developing claw lesions based on the entries provided by the user and calculating as an outcome the ALP value which gives a perspective of the pig’s welfare and can be evaluated by the user (Figure 6).

The alteration of the data input can be done in real-time within the interface at any time allowing the user to test several scenarios within the farmer’s realistic economical possibilities.

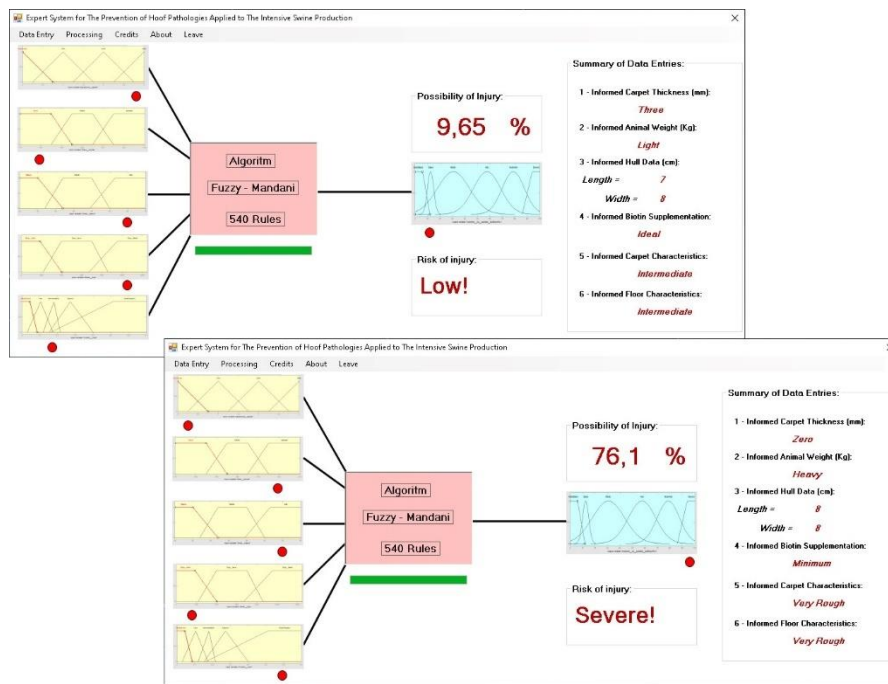


Figure 6. Risk of developing lesion resulting from the processing using two extreme scenarios

Similar systems have been reported for the prevention of some diseases such as a knowledge-based system for diagnosis of mastitis problems at the herd level was proposed by the ref. [12], the application of an expert system that provides a means of consultation imitating the reasoning process of an expert in solving complex problems concerning the health of cows reproduction proposed by the ref. [23] and the development of an “Expert System” based on a Fuzzy Logic model, designed to analyze the outcome a number of variables have on the performance of livestock production (milk and meat) in the Huasteca region of Veracruz in order to support the decision-making of a Sustainable Livestock Production Dynamic System (SLPDS) by the ref. [25].

Pneumonia and jaundice Expert’s Systems were proposed by the ref. [21] through the modeling of the knowledge and thinking process of a doctor. A Fuzzy Logic Controller is used to model the process and a genetic algorithm helps in the selection of a number of good rules from manually constructed large rule base, which is based on the opinion of ten doctors. According to the authors, once the rule base is optimized by the genetic algorithm (off-line), the system can diagnose the diseases on-line. The interface takes the symptoms as input variables and the output, grade of the disease, is determined.

Zovex, a zootechnical veterinary expert system to advise swine farms on animal health management was proposed by the ref. [11]. It is composed of two applicable functions: a vertical problem solver and a horizontal preventive screener. In the vertical function, a structured analysis of health, welfare or performance problems is executed, followed by advice for the solution of the problem. In the horizontal function screening of the pig fattening farm on a specific zootechnical domain for the presence of risk factors that sooner or later may cause problems is performed.

In the present system, claw health is the main concern as it affects the general performance of the animals and is not greatly explored as far as forces and pressure are concerned and how it interacts with other management conditions.

According to the ref. [20], flooring is of particular importance on claw health, because of pressure distribution and redistribution on claws. Uneven weight-bearing of hoof walls managed on hard floors (i.e. concrete) lead to pressure redistribution on claws and thus causes greater pressure concentration and stress on claws.

As stated in the ref. [4], the authors used 3 different thickness of rubber mat 1mm, 2mm, and 3mm to assess pressure redistribution and balance of boars' claws. The results showed a difference of 0,46 kg/cm² Net pressure (3,24 vs. 2,78 kg/cm² for the 1mm against 3mm rubber mattresses, $p < 0.0001$, by increasing the area under the foot from 30,7 cm² 41,9 cm², $p < 0.059$), strengthening the knowledge that the use of flooring systems that cushion and provides balance to pressures under the claw can prevent pressure concentrations and therefore the development of sole ulcers and other lesions favoring the onset of lameness.

The present expert system considers pressure balance as one of the most important factors affecting claw health and hence, the outcome is greatly affected by choosing an appropriate thickness combined with roughness of the surface.

Roughness is explored by the references [7] and [22]. It can be harmful in extremes of either softness or roughness according to authors. Softness causes the animal to slip and fall whereas extreme roughness can be abrasive to the point of fracturing the horn tissue of the sole. Several roughness types of concrete were tested by her study providing a great contribution to the system. Also, the use of rubber floors that provide more friction and more compressibility than concrete can increase the speed of cow locomotion and reduce chances of slipping.

Both increased surface roughness and increased compressibility seem to contribute to this effect, although floors that are too soft may not provide secure footing. The system uses this knowledge according to friction coefficient provided by the authors adding risks to either extreme and reducing risks as the coefficient of friction reaches a secure level around 0.25 to 0.45 approximately.

The coefficient of friction is input in the type of flooring provided by the software. This way the user can choose the type of flooring on the software by selecting it from several types provided by the software through sample images of flooring types either concrete types as well as rubber types and its coefficient is associated automatically.

The association of biotin levels and flooring type improvements plays a great role in the overall performance of the system. Data supporting claw health improvement with the use of supplementation of biotin is described in several studies as we can find in the references [3]; [26] and [8].

Supplementary biotin affected the structure of the coronary epidermis; there was an increase in the density of the horn tubules in the stratum medium, the horny scales in the stratum medium were more tightly packed and the tubules were more clearly defined in the pigs receiving biotin. The width of the band of intertubular horn adjacent to the laminae was greater in the claws of control pigs [14].

Levels of biotin were added to the system as minimal, light and ideal supplementation levels ranging from 0 to 1200 ug/kg, reducing risks as the levels are increased according to the findings of the studies mentioned above and other authors ([13] and [18]).

The association of nutritional supplementation of biotin and flooring (associated with abrasion coefficients) was tested in several scenarios and performed consistently with the findings mentioned in the literature.

The other variables namely, claw area and animal weight are just as important but affects the system at a smaller level. A large claw area has an overall better force and pressure distribution just as the animal weight since heavier animals with smaller claws generate more pressure concentrations than otherwise. On the other hand, the trends imposed by these variables can be easily mitigated when associating carefully the type of mattress and improving supplementation of biotin and therefore represents a lower risk in the overall system.

The contribution of animal weight and claw area was obtained from the experiments as part of the study used to develop the software and others ([4]; [6]; [5] and [24]).

The systems overall performance seemed to attend the trends tested both in literature and in the field.

4. CONCLUSION

The software generated in this project, although counting on an algorithm developed with the recent knowledge in the field of animal handling and caring, as well as facilities designs for swine production counts on an accessible and practical user-friendly interface designed specially to auxiliary all types of users.

Its use permits to create conditions to prevent hoof pathologies frequently caused by inadequate techniques of animal handling and inappropriate facilities as well as fatly nutrition methods allowing to the correction of several parameters improving animal health and longevity. This software presents itself 100% functional and its performance can be evaluated by a wide range of professional previously mentioned.

Future recommendations demand field testing for fine adjustments and should be encouraged in further research.

5. ACKNOWLEDGMENT

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