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Module-A Sensor Performance Tests Used in Laboratory-Type Silage Production, Data Acquisition and Control System

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ABSTRACT

The primary objective of this study is to investigate the performance of sensors integrated into the laboratory-type silage production, data acquisition, and control system. The system is a Programmable Logic Controller (PLC) controlled and multi-sensor based system designed to enable numerous studies aimed to improve silage quality. It consists of grinding, weighing, silo, data acquisition, and control units. It provides the capability to apply/change/simulate various parameters during the silage production process. The silo unit is composed of two modules, module-A (compression principle) and module-B (vacuum principle). This research focuses on measurements conducted with plexiglass silos (24.5 cm^3) in the module-A unit. This silos were equipped with oxygen sensor (±0-100 %), carbon dioxide sensor (0-5000 ppm), temperature sensor (±0.53 °C, -10 – 80 °C), humidity sensor (0-100 %), pH sensor (2-12), and pressure sensor (± 1000 mbar). The research utilized second-crop silage corn material with a dry matter content (DM) of 32%. Four different compaction forces were applied during the experiments. In the study, sensors with analog output values were used and the average of the data recorded as one data per second was taken. The data were displayed and monitored on the HMI operator panel programmed with GOP HMI editor software and stored in Excel format. The measurements were conducted during the silage (aerobic) and post-silage (anaerobic) periods. To ensure the accuracy of the measurement results obtained in the research, sensors widely used in industrial applications with calibration certificates were preferred. However, issues related to the oxygen and carbon dioxide sensors were encountered. The oxygen sensors used in the preliminary tests of the study had a 3-month service life. Due to this situation, the sensors were replaced with longer-lasting oxygen sensors instead of frequently changing them. In addition, the study encountered a carbon dioxide value above the predicted carbon dioxide amount, and the capacities of the carbon dioxide sensors were increased accordingly in the preliminary tests of the study. During measurements conducted at the compression stage in module-A, the pressure values varied between 0.34-0.67 bar with increasing compaction force. The temperature ranged from 16-33 °C, humidity from 60-100 %, pH from 5.8-5.6 O_2 level from 8.1-0 mmol L^{-1}, and CO_2 level from 0-40 mmol L^{-1}. The measured value ranges in silage varied depending on the duration of silage, and accurate measurements were obtained in the desired direction. Sensor placements were updated considering measurement accuracy.

Laboratuvar Tipi Silaj Yapımı, Veri Toplama ve Kontrol Sisteminde Kullanılan Modül-A Sensör Performans Testleri

Araştırma Makalesi

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ÖZ

Bu çalışmanın temel amacı laboratuvar tipi silaj yapımı, veri toplama ve control sistemine entegre edilen sensörlerin performanslarını incelemektir. Sistem, silaj kalitesinin iyileştirilmesine yönelik çok sayıda çalışmaya olanak sağlamak üzere tasarlanmış, PLC kontrollü ve çoklu sensör tabanlı bir sistemdir. Kıyma, tartım, silolama, veri toplama ve kontrol ünitelerinden oluşmaktadır. Silaj yapım prosesi sırasında çeşitli parametreleri uygulama/değiştirme/simüle etme yeteneği sağlar. Silolama ünitesi modül-A (sıkıştırma ilkesi) ve modül-B (vakum ilkesi) olmak üzere iki modülden oluşmaktadır. Bu araştırma, modül-A ünitesindeki pleksi silolar (24,5 cm^3) ile yapılan ölçümlere ilişkin çalışmaları içermektedir. Bu silolar oksijen sensörü (%±0-100), karbondioksit sensörü (0-5000 ppm), sıcaklık sensörü (±0,53 °C, -10 – 80 °C), nem sensörü (%0-100), pH sensörü (2-12) ve basınç sensörü (± 1000 mbar) ile donatılmıştır. Araştırma ikinci ürün silajlık mısırda (%32 KM) yürütülmüştür. Denemelerde dört farklı sıkıştırma kuvveti uygulanmıştır. Çalışmada analog çıkış değerlerine sahip sensörler kullanılmış ve saniyede bir veri olarak kaydedilen verilerin ortalaması alınmıştır. Veriler GOP HMI editör yazılımı ile programlanan HMI operatör panelinde görüntülenip izlenmiş ve Excel formatında depolanmıştır. Ölçümler silaj (aerobik) ve silaj sonrası (anaerobik) dönemlerde gerçekleştirilmiştir. Araştırmada elde edilen ölçüm sonuçlarının doğruluğundan emin olmak için kalibrasyon sertifikalı ve endüstriyel uygulamalarda yaygın olarak kullanılan sensörler tercih edilmiştir. Ancak oksijen ve karbondioksit sensörlerine ilişkin sorunlarla karşılaşılmıştır. Çalışmanın ön testlerinde kullanılan oksijen sensörlerinin 3 aylık kullanım ömrüne sahip olduğu belirlenmiştir. Bu durumdan dolayı sensörleri sık sık değiştirmek yerine daha uzun ömürlü oksijen sensörleri ile değiştirilmiştir. Ayrıca çalışmada öngörülen karbondioksit miktarının üstünde bir karbondioksit değeri ile karşılaşılmış olup, çalışmanın ön testlerinde karbondioksit sensörlerinin kapasiteleri buna göre artırılmıştır. Modül-A'da sıkıştırma aşamasında yapılan ölçümlerde, sıkıştırma kuvvetinin artmasıyla birlikte basınç değerleri 0,34-0,67 bar arasında değişmiştir. Sıcaklık 16-33 °C, nem %60-100, pH 5,8-5,6 O_2 seviyesi 8,1-0 mmol L^{-1} ve CO_2 seviyesi 0-40 mmol L-1 arasında değişim belirlenmiştir. Silajda ölçülen değer aralıkları silajın süresine göre değişiklik göstermiş ve istenilen yönde doğru ölçümler elde edilmiştir. Ölçüm doğruluğu dikkate alınarak sensör yerleşimleri güncellenmiştir.

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1. Introduction

Silage is an important source of roughage widely used in animal nutrition. Therefore, the production, construction technique, and quality of silage material hold significant importance. In Turkey, the maize plant, which is widely cultivated as silage material, is used for both first and second crop silage. In silage production, there are various methods such as bunker silo, pile type silo, bale silage, and silage bags. Failures or deficiencies in silage production techniques can lead to significant problems, such as the deterioration in silage quality. There are many factors that influence the production of high-quality silage. Potential risks of problems will increase if the management challenges of these factors are not overcome. These factors could include, for example, the producer having different types of tractors, variations in operator skill levels and training, usage of compaction equipment with different masses, the duration and experience of using the equipment, conditions related to the product and harvesting period, and the application techniques used in silage. These factors have been examined by many researchers. In addition to product-related factors such as material type, moisture content (Roy et al., 2001; Holmes and Muck, 2004; Jones et al., 2004; Wang, 2012), harvest period, cutting frequency, particle size (Shaver, 1990; Ruppel, 1993; Shinners et al., 1994), there are also parameters related to the use of compaction equipment, such as its mass, tire types, tire pressure, compaction duration, applied compaction force (Ruppel, 1993; Ruppel, 1997; D'Amours and Savoie, 2005; Oelberg et al., 2005), layer thickness (Muck and Holmes, 1999; Oelberg et al., 2005), tire size, tire type, tire pressure, applied force, and compaction duration (Roy et al., 2001; Muck et al., 2004), Oxygen, carbon dioxide (Li et al., 2016; Shan et al., 2016; Tan et al., 2020), density (Ruppel et al., 1995; Muck and Holmes, 2000; Muck and Holmes, 2000; Roy et al., 2001; Muck et al., 2004; Savoie et al., 2004; D'Amour and Savoie, 2005; Craig and Roth, 2005; D'Amour and Savoie, 2005; Oelberg et al., 2005; Visser, 2005; Sun et al., 2010; Wang, 2012; Latsch and Sauter, 2013, Hoffman and Geyer, 2014; Li et al., 2016; Tan et al., 2018). It is known that the inability to manage all these factors correctly in the silage technique applied negatively affects the quality of silage. For this reason, the whole of the harvesting of the silage material, the transportation phase, filling-compressing and closing the silo should be considered as silo management. Examining all these parameters in field conditions, obtaining accurate data within a short period, and conducting numerous measurements in silo management can be quite challenging. For this reason, laboratory-scale studies are becoming increasingly important.

In this research, it is aimed to examine the measurement performances of the sensors placed in the laboratory type silage production, data collection and control system developed by us. Oxygen, carbon dioxide, pH, temperature, humidity and pressure sensors with wired/wireless communication are installed in the developed system. These factors can give information about silage quality and fermentation process. The numbers and qualities of the sensors can be increased or decreased according to the parameters desired to be measured, and their positions can be changed. The main purpose of this study is to test the performance of the sensors placed in the module-A unit, where the compression principle in the system is used. At the end of the study, detecting the problematic sensors and/or replacing them with more compatible sensors with different features, changing the location or measuring point, choosing a wired or wireless sensor, or methods with different approaches are suggested.

2. Material and Method

In the research, the most commonly used corn plant for silage production has been utilized as the silage material. Laboratory-scale silage production, data collection, and control system developed through the TÜBİTAK 1002 project have been employed to collect data from the material. In the system, it is possible to carry out silage studies based on the two fundamental principles used in silage making technique: the principle of compression and the principle of vacuuming.

The basic units of the system are shown in Figure 1.

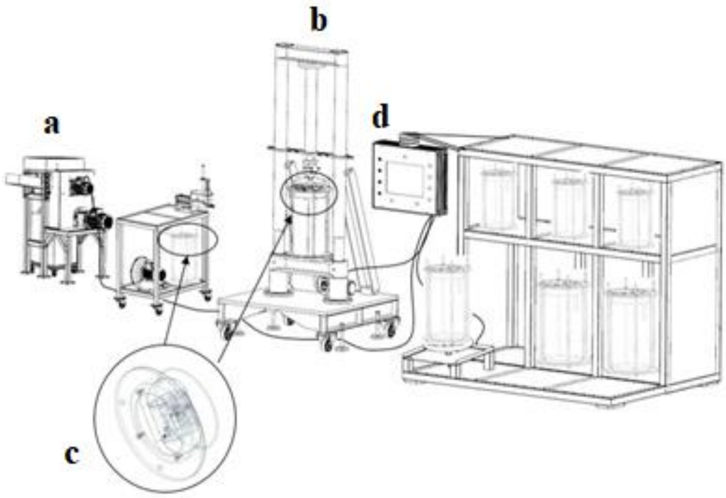


Figure 1. Laboratory type silage making, data collection and control system

The system primarily consists of four main units. These are;

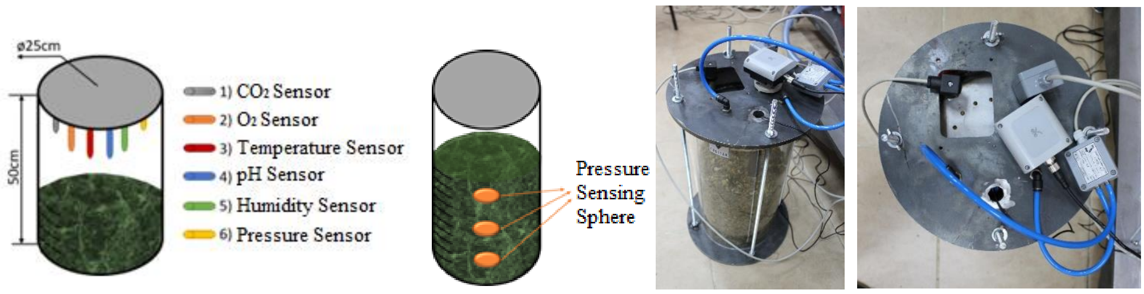
a. Chopping unit
b. Ensiling unit
c. Data collection unit
d. Control unit

In the chopping unit, the materials are shredded. This unit has been developed to adjust the chopped particle size achievable with forage harvesters during corn harvesting. This unit has been developed to adjust the shredded piece size that can be obtained during corn harvesting with forage harvesters. There are two chopping blades on the rotor with a hardness value of 44 HRC. The length of the chopped particle size can be adjusted precisely.

The ensiling unit consists of two main modules; Module-A constitutes the ensiling unit using the compression principle, and Module-B constitutes the ensiling unit using the vacuuming principle. Four different compaction forces (500, 1000, 1500 ve 2000 N) were applied during the experiments in Module-A.

The data acquisition unit consists of various sensors. According to the desired data and system requirements, sensors with appropriate features can be selected and added to this unit. Furthermore, the positioning and placement of sensors are crucial to achieve accurate data measurement during and after the compaction process in the silo. In this research, the sensors have been placed within a specially designed silo cover. The Type1, Type2 and sensor placements conducted for Module-A are illustrated in Figure 2.

Additionally, real-time measurements of weight and time can also be performed in the system. As of June 2, 2021, the laboratory-scale silage production, data collection, and control system have been granted the TR 2021 009131 B Patent Certificate (NKU, 2022-Tan, F., Dalmış S.İ, Okur E., Dalmış F.).



(a). Type2 (b) Type1 (c) Sensor placements

Figure 2. (a) Type2; (b) Type1; (c) Module-A sensor placements

The data collected from sensors can be recorded in the data control unit and stored at desired time intervals. The control unit of the system is PLC-based and can be operated both manually and automatically.

The control unit consists of a GMT CNT GLC-196T CPU module, two GXM-42A analog input/output modules, one GXM-40A analog input module, and one GXM-40U load cell module. The measured values are displayed on a 7” TFT touchscreen operator screen within the system and set value entries can be made through this screen. The data collected in real-time is recorded on a USB memory stick inserted to the USB port of the screen without the need for computer connection, thanks to the trend functions created during the screen programming.

The PLC is powered by 24V direct current (DC) energy. The PLC and expansion modules communicate with the operator panel via RS485 communication standard using the Modbus function block defined in the PLC program. Part of the PLC program and the Modbus function block used in this application are shown in Figure 3. In the design of the system, two Windows-based softwares were utilized: 1-Endasoft Editor Program, and 2-GOP HMI Editor Software.

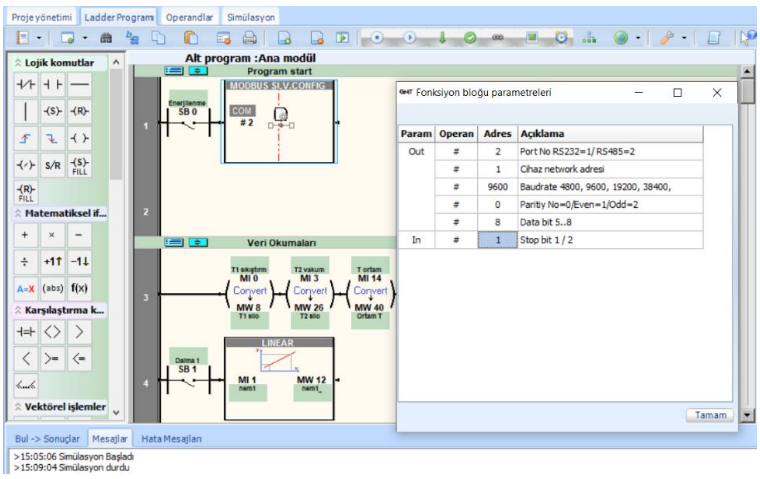


Figure 3. Part of the PLC program and the Modbus function block

The PLC program was created using the ladder diagram method in the Endasoft Editor Software and then loaded onto the PLC. In the GOP HMI Editor Software, pages are designed according to the system's requirements to display incoming process data on the screen. Additionally, these pages are used to send user commands to the system through the operator panel.

The data in the system possesses three distinct characteristics. These are:

- Fixed set of data (compaction force (kg), data sampling period (1 data / 1 s)),
- The data acquired through sensors (temperature, humidity, oxygen, carbon dioxide, pressure, pH, ambient temperature, pressure difference, mass)
- Variable data (such as material type, quantity, dry matter content, particle size)

2.1. Sensor Types

In the system, six different types of sensors have been used for data acquisition (Table 1).

Table 1. Sensor types and features

Type2				
Sensor	**Analog output**	**Type**	**Confidence interval**	**Principle**
Temperature	4-20 mA	2	± 0.53°C (-10° - 80°C)	Thermocouple
Humidity		2	0-100 % RH	
Pressure	4-20 mA	2	± 1000 mbar	Piezo-resistive
pH	4-20 mA	2	2-12	Potentiometric
Oxygen	4-20 mA	2	0-100 % vol. ±2	Electrochemistry
Carbon dioxide	4-20 mA	2	0-5000 ppm ±3	NDIR
Type1				
Sensor	**Analog output**	**Type**	**Confidence interval**	**Principle**
Temperature	wireless	1	-20 ºC, +50 ºC	Thermocouple
Pressure	W/4-20 mA	1	0-2.5 bar (%0.5)	

Type1 sensors have been added to the system as temperature and pressure sensors. This type of sensors communicates through wireless connections. Type 1 UA-002-64 Hobo pendant temperature data logger holds approximately 52K measurements of 10-bit readings with a range of -20° to 70°C. MPS500 series pressure sensors with a measurement range of 0-25 bar are preferred as type1 pressure sensors. Type1 pressure sensor belongs to the pressure measurement system especially developed for bulk materials. The load cells used in the system are explained in module A.

2.2. Plexiglass silo

Plexiglass tubes of different heights and diameters were used as silos. In this research, a 50 cm x 25 cm silo has been utilized for Module-A compression unit. The properties of plexiglass silo material are provided in Table 2. An example of the plexiglass tube and the developed plexiglass silo are shown in Figure 4.

Figure 4. Plexiglass silo and plexiglass tube sample

Table 2. Properties of plexiglass

Mechanical properties	**ASTM**	**Values**
Specific weight	D-792	1.19
Tensile strength	D-638	11.250
Tensile strength elongation	D-638	6.4
Compressive strength	D-695	18.00
IZOD impact resistance	D-256	0.037
Flex module	D-790	475000
Thermal properties		
Linear coefficient of thermal expansion	D-696	0.000042
Heat distortion at 264 psi		180
Optical properties		
UV transmission @320 nm	D-1003	>80
Haze	D-1003	<0.5

2.3. Load Cell Types

Three load cells with different capacities (50-200-5000 kg) were utilized in the system. A 5000 kg load cell was employed for the compaction force in Module-A. Load cells that detect the weight changes were connected to the GMT GXM-20L load cell expansion module.

2.4. Module A

The compression principle applied in silo construction (bunker silage, pile type silage, bale silage production) is a module that enables implementation under laboratory conditions (Figure 5). To generate the compression force in the system, a hydraulic power supply with a capacity of 6 liters and operating at 380V three-phase voltage was used. A pressure relief valve is used to limit or control the pressure in the developed system. Additionally, a flow control valve has been employed to control the movement speed of the cylinder.

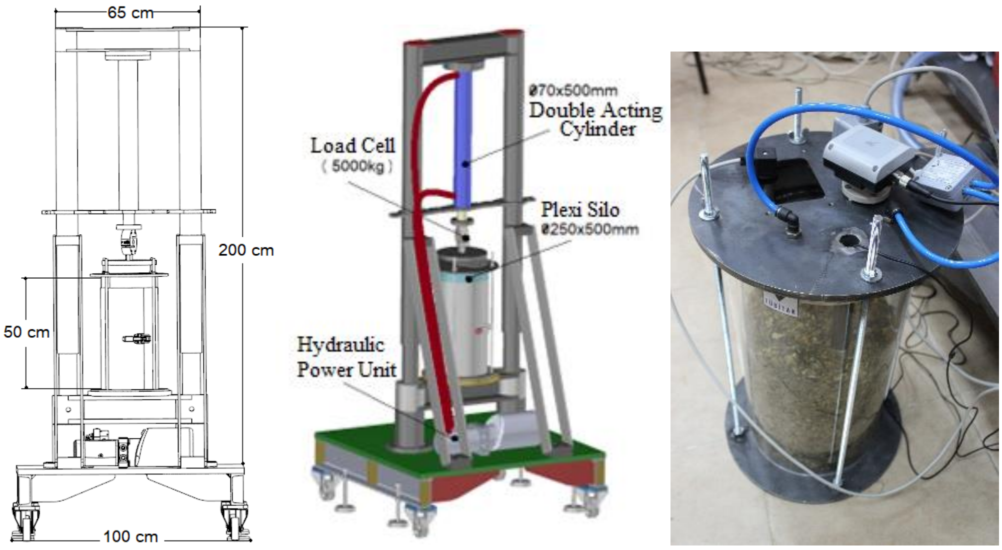


Figure 5. Module-A

The measurements conducted in the silo used in Module A can be tracked through the data monitoring screen shown in Figure 6 and they are also recorded in the flash memory.

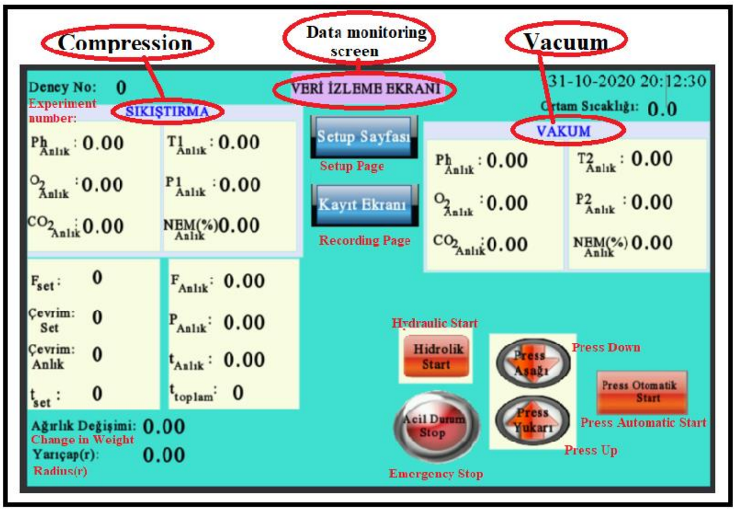


Figure 6. The main page of the HMI: Data monitoring screen

This is also significantly important in terms of detecting potential problems early. In addition, sensor data related to Module-B can also be monitored on the screen along with Module-A.

2.5. Time Measurements

Time-related measurements, dependent on the processes implemented in Module-A in the system, are defined as follows:

Total Time (Ts): The duration between the start and end of the experiment.

Cycle Time (Tc): Total time for hydraulic cylinder descent, force application, and retraction.

Application Time (Tu): The duration during which the piston remains on the silage surface.

Wait Time (Tb): The duration during which the piston remains in the upper position.

Cycle Count (Cs): The number of cycle times applied between the start and end of the compression process in a silo.

Applied Force (F): The force that can be manually or automatically adjusted from the screen and is applied in Module-A (max. 5000 kg). In this research, the performances of Module A measurements were evaluated in the system developed by us. The data acquisition from sensors placed on a specially designed cover and recording features of the gathered data were examined.

3. Results

Data acquisition has been successfully achieved from all the installed sensors. Both the accuracy of the data obtained from the sensors used in the system and the accuracy of the measurement results from the sensors placed on the specially designed cover have been tested. In laboratory studies, the usage of the selected sensors for silage production has been evaluated among themselves. When the total time (Ts) is taken as 100%, Tc time forms 75% and the wait time (Tb) forms 25% of the time interval. Tc and application time have been carried out similarly in all silos.

3.1. Pressure Sensors

The compaction pressure data based on compression time (hours) detected by the pressure sensors during the silage process is shown in Figure 7, while the data obtained during the fermentation process is displayed in Figure 8.

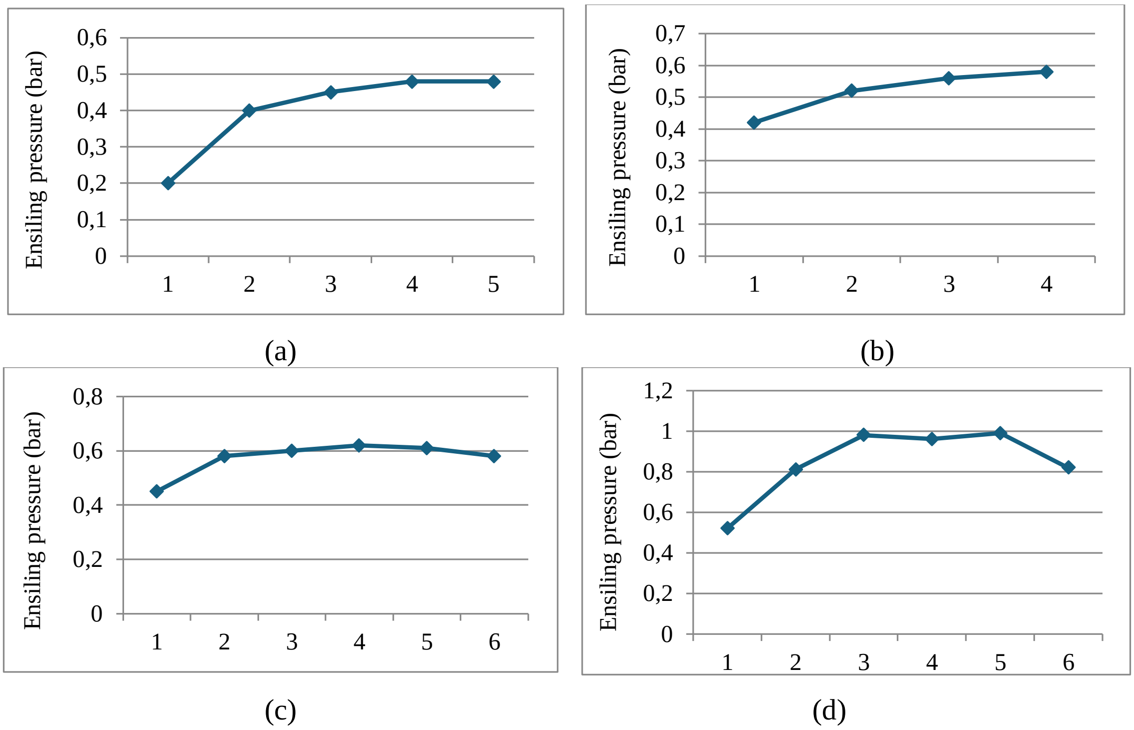


Figure 7. Pressure sensor data based on the force applied during the ensiling process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

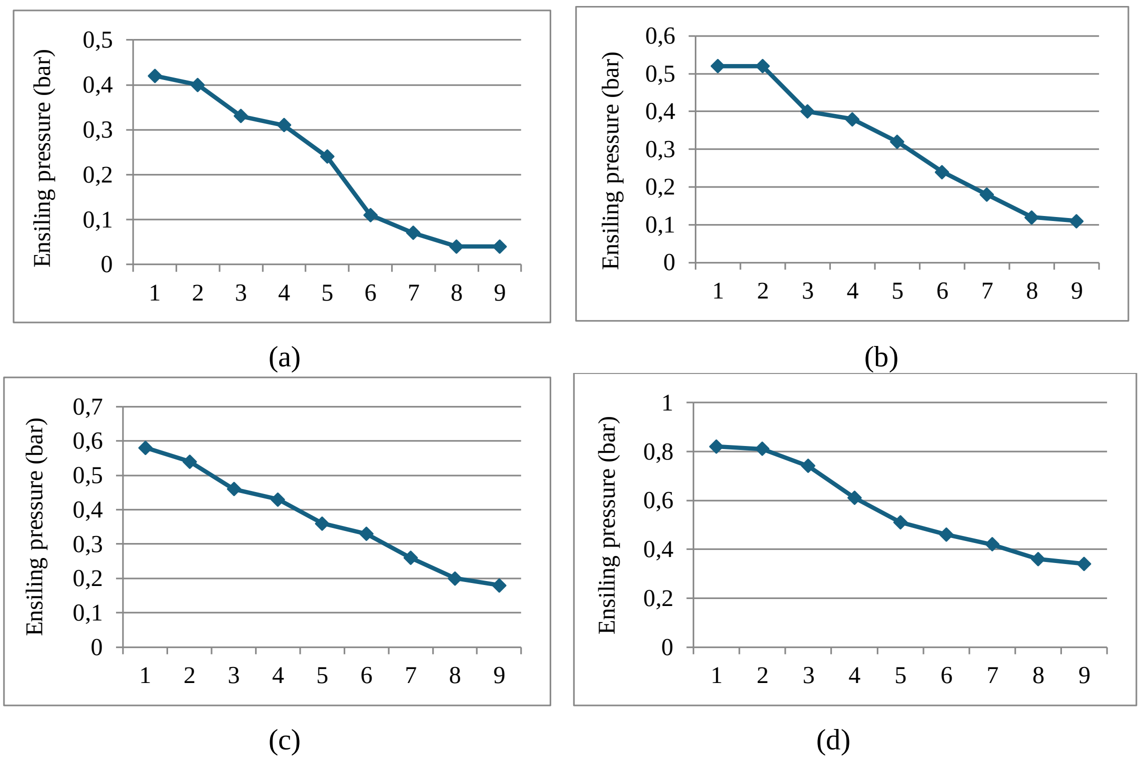


Figure 8. Pressure sensor data based on the force applied during the fermentation process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

In order to examine the changes in compaction force, measured by pressure sensors, plexiglass silos containing corn harvest with a dry matter content of 32% were compressed with four different forces. As seen in Figure 7, the measured pressure data increased due to the increase in the applied force during the ensiling phase. This situation leads to the conclusion that pressure sensor data has been successfully obtained during the compression process.

It is expected that the pressure data will show a decreasing trend when the effect of the compaction force is removed from the material (Figure 8). Based on the measurement results, it has been concluded that the data obtained from the sensors are accurate and the current sensors can be used for this purpose. On the other hand, it has been determined that the location where the sensor is placed is suitable for measurement.

3.2. Temperature Sensors

Data acquisition test from temperature sensors was carried out during ensiling and fermentation stages. Temperature sensors were placed on the specially designed silo cover. The temperature changes in the material under the effect of different applied force were investigated. The temperature data (°C) collected during the ensiling process is shown in Figure 9, whereas the temperature data (°C) detected during the fermentation process is illustrated in Figure 10.

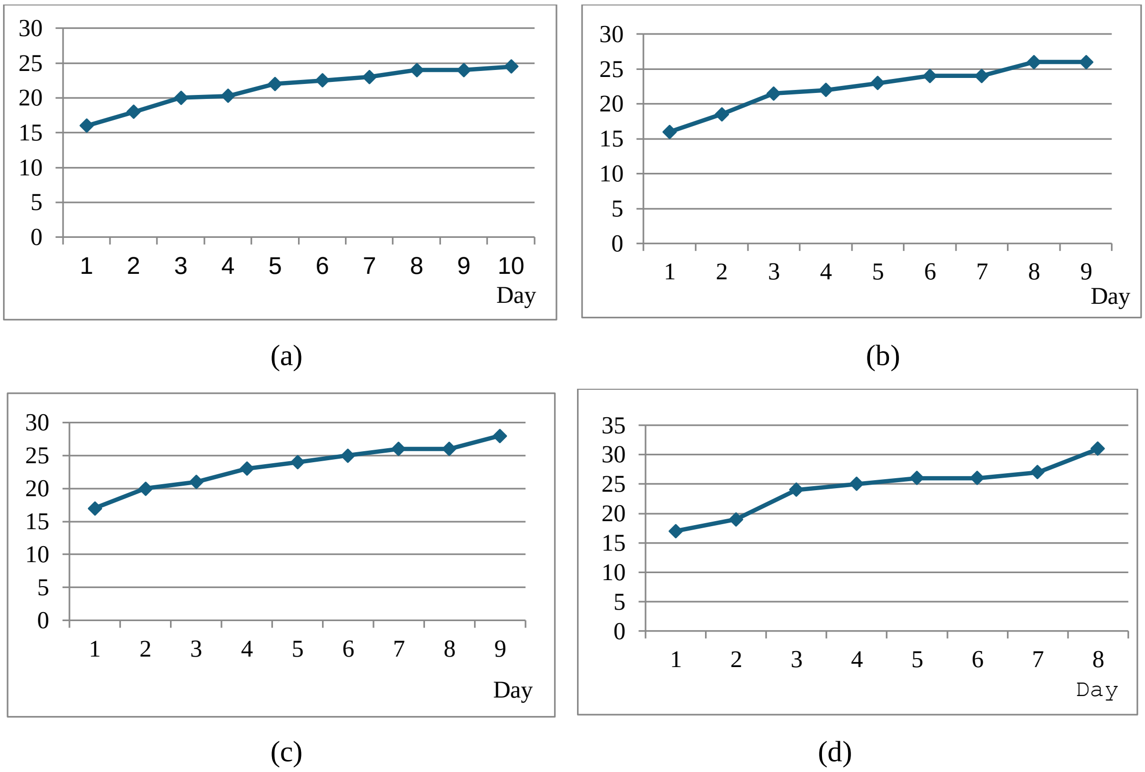
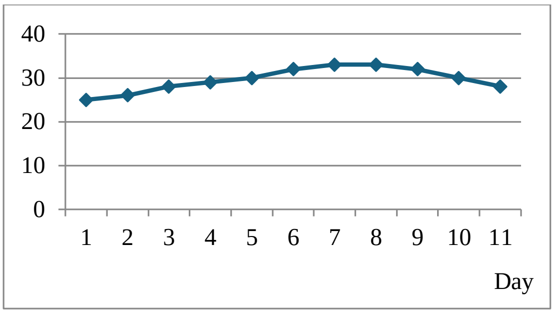
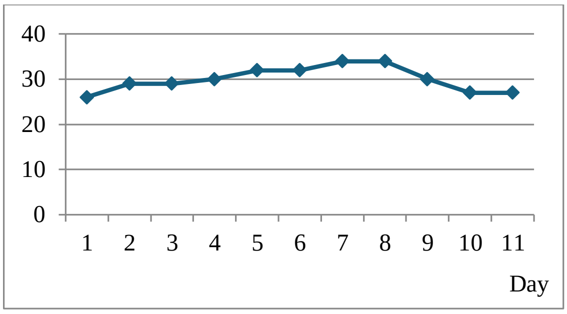


Figure 9. Temperature sensor data based on the force applied during the ensiling process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

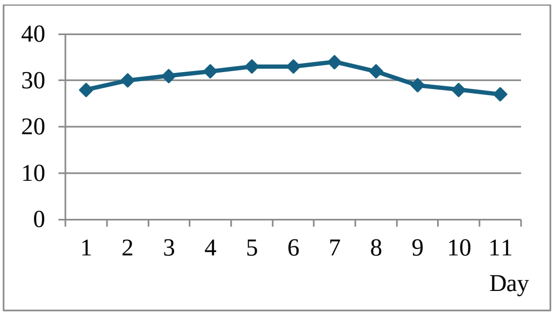
As observed from Figure 9, the temperature data also exhibits an increasing trend with the increase in the applied force during the ensiling process. This situation is interpreted as a successfully data acquisition from the temperature sensor during the compaction process.



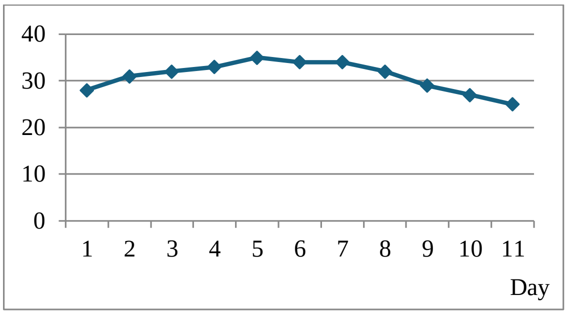
(a)



(b)



(c)



(d)

Figure 10. Temperature sensor data based on the force applied during the fermentation process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

With the effect of the fermentation process, it is expected that the temperature values of the ensiled materials will first tend to increase and then decrease (Figure 10). According to the obtained measurement results, it was concluded that the sensor measurements were accurate and the existing sensors could be effectively used for this purpose. Similar data were obtained in temperature measurements performed with wireless sensors. Additionally, it has been determined that the placement of the sensor is suitable for measurement. Measurement intervals are pre-set for both sensors. The advantage of the wireless sensor is that it can be used without any problems within the material and in many different positions.

Besides, its disadvantages are that during data acquisition, the data cannot be displayed in real-time, and the sensor needs to be taken out of the silage and the data can be read after transferring it to the computer. The disadvantages of using wireless sensors are as follows:

- Inability to view data in real-time during the data collection process
- The need to be taken out the sensor from inside the silo
- Necessity to transfer sensor data to a computer and read it after retrieval

In this case, the biggest risk factor is that if the sensor fails to work for any reason, there will be no data available. This situation would require repeating the process.

3.3. Humidity Sensor

Data acquisition test from humidity sensors was also carried out during ensiling and fermentation stages. Humidity sensors are also placed on the specially designed silo cover in the system. Humidity content changes in the material were observed under the effect of different applied force. The humidity content data (%) detected by the humidity sensors during the ensiling process are presented in Figure 11, while the humidity content data (%) recorded during the fermentation process are shown in Figure 12. As seen in Figure 11, it can be observed that during the ensiling process, the increase in applied force corresponds to a rising trend in humidity sensor data, which is linked to the increasing water content. The moisture sensor data also exhibited a decreasing trend in accordance with the decreasing humidity content over time. This indicates a successfully data acquisition from the humidity sensor during the compaction process.

In Figure 12, a decrease in humidity values is expected due to the effect of fermentation process in the silage materials. When the data obtained from the humidity sensor were examined, the following results were obtained:

- The humidity sensor measurements are accurate,
- The current sensor type is suitable for this purpose,
- The placement of the sensor is appropriate.

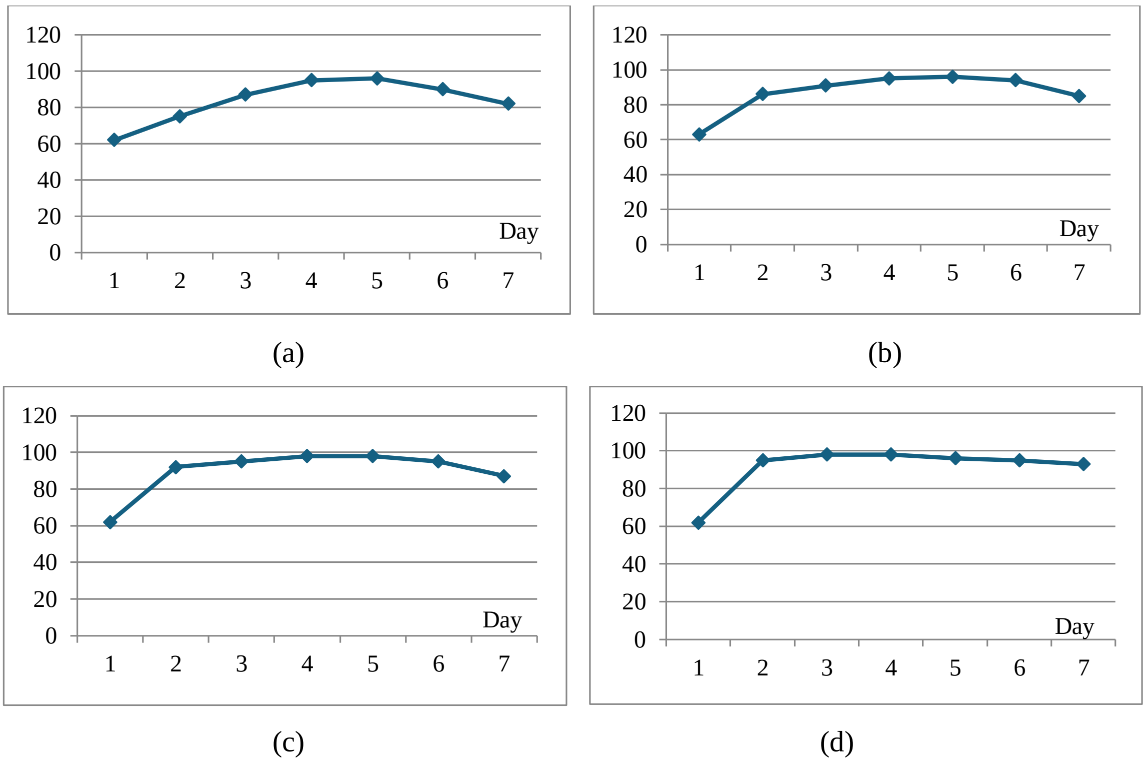


Figure 11. Humidity sensor data based on the force applied during the ensiling process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

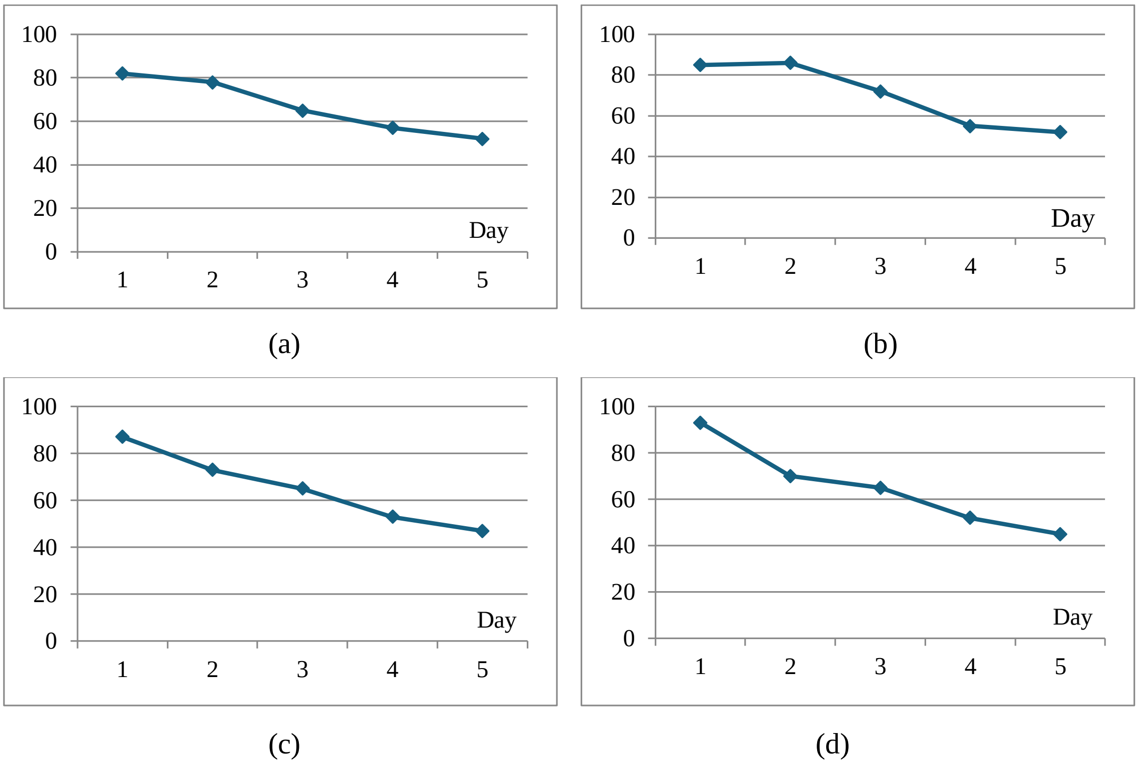


Figure 12. Humidity sensor data based on the force applied during the fermentation process (a) F500 N,
(b) F1000 N, (c) F1500 N, (d) F2000 N

3.4. pH Sensors

The pH sensor is also placed on the specially designed silo cover in the system. The sensor test was conducted in both ensiling and fermentation stages. The changes in pH of the material were monitored under the influence of different applied forces. Due to minimal variations in pH measurements under the applied force effects, a single measurement was taken for both stages. The pH data gathered from the pH sensors during the ensiling process is shown in Figure 13a, and the pH data collected during the fermentation process is displayed in Figure 13.

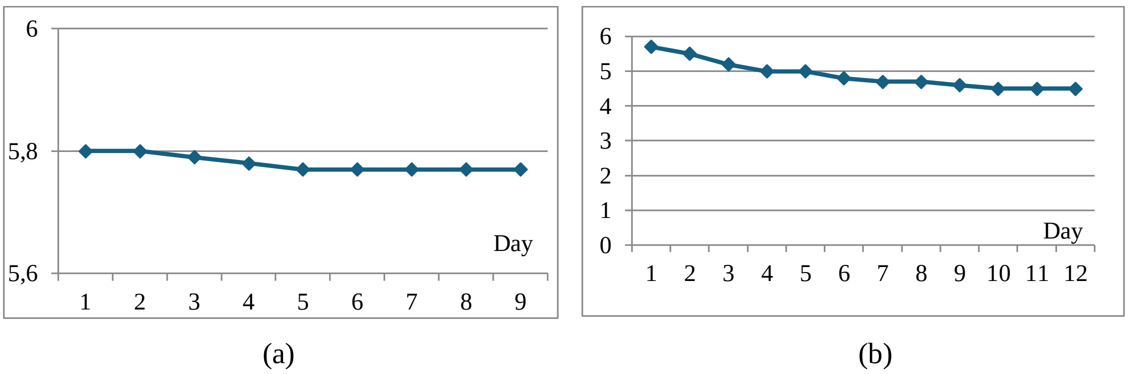


Figure 13. PH sensor data based on the force applied during both ensiling (a) and fermentation process (b)

It is expected that the pH value tends to decrease with the applied compaction force. This situation indicates that the silage quality and fermentation progress are improving positively. It was observed that the fermentation progress and sensor data values tended to decrease with time. This situation is interpreted as a successfully data acquisition from the PH sensor during the compaction process.

3.5. Oxygen (O_2) Sensor

Data acquisition test from O_2 sensor was carried out during fermentation stages.

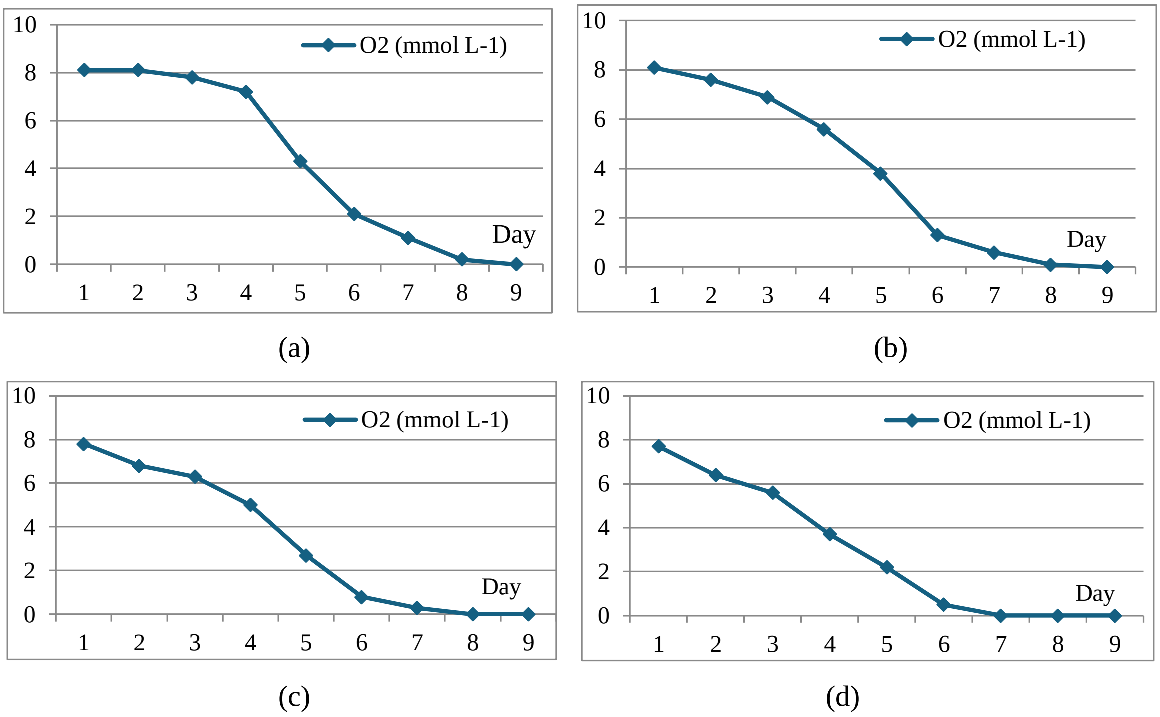


Figure 14. O_2 sensor data based on the force applied during the fermentation process (a) F500 N, (b) F1000 N, (c) F1500 N, (d) F2000 N

Oxygen values were not taken into account during the ensiling phase as they contain ambient values. The oxygen (O_2) sensor is also placed on the specially designed silo cover. Oxygen changes in the material were observed under the effect of different applied force. O_2 data obtained during the fermentation process is shown in Figure 14. It is expected that the Oxygen value tends to decrease with the applied compaction force. This situation indicates that the silage quality and fermentation progress are improving positively. The O_2 sensor has been interpreted as successful in data acquisition. However, due to the short lifespan of the sensor, it is necessary to replace it with a new one at 3-month intervals. For this reason, it was decided to test different oxygen sensors for gathering oxygen data.

3.6. Carbon dioxide (CO_2) Sensors

The sensor test was conducted in both stages. However, due to obtaining different values in the measurements, sensor specifications and positions were reviewed. Sensor calibration is not fully completed. Therefore, a different CO_2 sensor was purchased. However, since the measuring ranges of this sensor were below the expected value, the increased CO_2 values could not be measured. However, since the input measurement range of this sensor is smaller than the actual value to be measured, carbon dioxide levels of the silage could not be measured. The carbon dioxide level in the material is expected to increase rapidly in the closed environment during the fermentation phase. As a result, a third and different sensor was purchased, but due to the completion of the silage processes, this sensor could not be included in the evaluation test in time.

4. Discussion and Conclusions

Sensors with both wired and wireless communication capabilities were tested on the system developed for silage studies under laboratory conditions. Data acquisition were successfully carried out using these sensors placed on the silo cover. Different types of sensors based on the principle of working were used in the system. Due to the fermentation phase is in a closed environment in silage production, the working conditions were quite challenging.

When the material is compacted during silage making process, the air pockets decrease in size, which in turn reduces the amount of oxygen present. During the fermentation process, an increase in CO_2 is observed due to the biological activity. Similar results were also observed and explained by Shan et al., (2016) and Li et al., (2017). An increase in CO_2 levels was detected, but the input measurement range of the sensor we have has proven inadequate for measuring carbon dioxide levels of the material. Especially during fermentation phase, Li et al., (2017) have demonstrated CO_2 levels increased 3- to 5-fold, accompanied by a pronounced decline of pH levels. Decreasing pH values are also accepted as an important indicator for high-quality silage. Oxygen value tends to decrease with the applied compaction force. The oxygen content tended to decrease under applied compaction forces. For quality silage, it is not necessary to have oxygen in the silo (Savoie et al., 2004). It shows that the O_2 sensor can make accurate measurements (Tan et al., 2020). Temperature distributions were measured at appropriate intervals according to the applied compaction forces. Similar results were also observed and explained by Tan et al., (2018). The sensors used in our study (temperature, humidity, pH, pressure and oxygen) were found to have sufficient capacity for silage studies. Only the CO_2sensor (5 000 ppm) did not have sufficient capacity for silage studies. It was found to have insufficient capacity due to the presence of CO_2 at values higher than the maximum measurement range. Therefore, it had to be replaced with a sensor with a high range of measurement capacity (40 000 ppm). The oxygen sensor is a sensitive sensor and is located in a closed box. When measuring, the box is opened and removed. These types of sensors provide a 3-month lifespan for an accurate and calibratable measurement. Due to this situation, the sensors were replaced with longer-lasting oxygen sensors instead of frequently changing them.

It was concluded that the CO_2 sensor must be replaced with a new one by extending the input measuring range and the oxygen sensor must be replaced with a long-life one.

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Statement of Conflict of Interest

The authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

Abbreviations

CO_2: Carbon Dioxide

O_2: Oxygen

DM: Dry matter

HMI:Human Machine Interface

F: Applied compaction force

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