Journal homepage
www.ajas.uoanbar.edu.iq
Anbar Journal of Agricultural Sciences
(University of Anbar – College of Agriculture)

USING EVAPORATIVE COOLING AND PACKAGING TO STORE EGGPLANT CROPS

M. Sh. M. Al-Yasari **S. B. S. Al-Badri ***

College of Agricultural Engineering Sciences University of Baghdad.

***Correspondence to:** Samir B. Salman Al-Badri, College of Agricultural Engineering Sciences, University of Baghdad, Iraq.
Email: samir.albadri@coagri.uobaghdad.edu.iq

Article info

Received: 2024-07-30
Accepted: 2024-10-23
Published: 2024-12-31

DOI-Crossref:
10.32649/ajas.2024.141807.1363

Cite as:
Al-Yasari, M. Sh. M., and Al-Badri, S. B. S. (2024). Using evaporative cooling and packaging to store eggplant crops. Anbar Journal of Agricultural Sciences, 22(2): 1581-1593.

Abstract

This research supports the UN's 2030 Agenda and its goals of ending poverty and hunger. Fruit and vegetable (FandV) lose their freshness and weight when stored at unsuitable temperatures and relative humidity. This study was conducted in Baghdad governorate, located at latitude 33.3128057 and longitude 44.3614875, in the Karrada region from February 27 to April 17, 2024. It compared the effectiveness of different storage technologies, including evaporative cooling, various air velocities, and diverse packaging methods, against sustainable and nonpackaging approaches. The study employed an air cooler with a volume of 2000 ft^3/s and insulated packaging. Temperature and relative humidity were recorded in the storage environment every five seconds using an Arduino system equipped with a DHT-22 temperature and humidity sensor. Analysis of the data revealed that evaporative cooling significantly extended eggplant shelf life and reduced weight loss when combined with effective packaging methods. The average SLD of CPS1 was 11 days and the lowest average WL was 3.86% at an average temperature and relative humidity of 16.02° C and 92.9%, respectively. The average SLD of CPS2 was 8 days while that for WL was 7.23% at an average temperature and relative humidity of 21.76° C and 94.08%, respectively. The multiple regression model explained 63% of the data, and the temperature coefficient was lower than for relative humidity, meaning that it is more significant than RH under the conditions of this experiment.

Keywords: Temperature, Relative humidity control, Shelf life, Sustainability, Poverty.

استخدام التبريد التبخيري والتعبئة لخزن محصول الباذنجان

محمد شاكر مهدي اليساري سامر بدري سلمان البدري *

كلية علوم الهندسة الزراعية، جامعة بغداد.

***المراسلة الى:** سامر بدري سلمان البدري، كلية علوم الهندسة الزراعية، جامعة بغداد، العراق.

البريد الالكتروني: samir.albadri@coagri.uobaghdad.edu.iq

الخلاصة

تحقيقا لأهداف التنمية المستدامة للأمم المتحدة 2030 وأهدافها في القضاء على الفقر والجوع. يأتي هذا البحث لإطالة مدة الخزن لمحصول الباذنجان وتقليل فقدان الوزن عند تخزينها. أجريت التجربة في محافظة بغداد، التي تقع جغرافيًا عند خط عرض 33.3128057 وخط طول 44.3614875، في منطقة الكرادة للفترة من 27 فبراير 2024 إلى 17 أبريل 2024. يقارن هذا البحث فعالية تقنيات التخزين المختلفة، بما في ذلك التبريد التبخيري وسرعات الهواء المختلفة وطرق التعبئة المتنوعة، مقابل الأساليب المستدامة وغير التعبئة والتغليف. تستخدم الدراسة مبرد هواء بحجم 2000 قدم^3/ الثانية والتغليف المعزول. تم تسجيل قياسات درجة الحرارة والرطوبة النسبية كل خمس ثوانٍ في بيئة التخزين عبر نظام Arduino المزود بمستشعر درجة الحرارة والرطوبة DHT-22. كشف تحليل نسبة فقدان الوزن ومدة التخزين أن التبريد التبخيري أدى إلى إطالة عمر تخزين الباذنجان بشكل كبير وتقليل فقدان الوزن عند دمجه مع طرق التعبئة الفعالة. أن متوسط SLD لـ CPS1 كان 11 يومًا، وكان أقل متوسط 3.86٪ WL عندما كان متوسط درجة الحرارة 16.02 درجة مئوية ومتوسط الرطوبة النسبية 92.9٪. كان متوسط SLD لـ CPS2 8 أيام، وكان متوسط درجة الحرارة 21.76 درجة مئوية، وكان متوسط الرطوبة النسبية 94.08٪، وكان متوسط 7.23٪ WL. يفسر نموذج الانحدار المتعدد 63٪ من البيانات ومعامل درجة الحرارة أقل من معامل الرطوبة النسبية، مما يعني أن درجة الحرارة أكثر أهمية من RH٪ في ظل ظروف هذه التجربة.

كلمات مفتاحية: درجة الحرارة، التحكم في الرطوبة النسبية، مدة الخزن، الاستدامة، الفقر.

Abbreviations used

Evaporative cooling system (EC); cooling eggplant (CE); cooling eggplant with packaging using speed 1 (CEPS1); cooling eggplant with packaging using speed 2 (CEPS2), fruit and vegetable (FandV); packaging (P); relative humidity (RH); speed 1 for air cooler (S1); speed 2 for air cooler (S2); shelf-life days (SLD); temperature (° C); non-cooling eggplant (NCE); non-cooling eggplant without packaging (NCENPS); non-packaging (NP); weight-loss percentage (WLP).

Introduction

Eggplant, a widely consumed plant rich in essential vitamins, faces challenges in maintaining its freshness and extending its shelf life (5). Improving food security and reducing waste (1) can have a cascading effect, raising living communities out of poverty, improving nutrition and health outcomes, and promoting more sustainable and equitable food systems (12). FandV in Iraq have short post-harvesting shelf-lives due to the lack of infrastructure for cold storage and electricity. Consumer decisions on the purchase of FandV depend on various subjective aspects (20). There is a strong correlation between objective and subjective methods used for evaluating FandV (21), with (4) noting the importance of color, shrivelling, and firmness. Local markets employ sustainable methods for marketing their products, which are heavily reliant on natural ventilation most of the time (19). Compared with ambient conditions, evaporative cooling has shown its effectiveness in improving the post-harvest quality of eggplants by maintaining lower temperatures and higher relative humidity (16). Besides fruit size, temperature is a critical influence in preserving eggplants with higher temperatures raising transpiration and shortening the shelf life of eggplants (9). The temperature and RH of storage conditions should be considered when handling FandV. For freshly harvested produce, any method that increases the RH of the storage atmosphere will reduce metabolic activities and water loss (15). Prompt storage of eggplants at low temperatures after harvest is essential for maintaining their quality.

The eggplants were refrigerated directly after harvest to prevent discoloration, rotting, calyx, and weight loss (11). When stored at T 11° C and 25° C for ten days, packaging weight loss was 7.75% for control, 10.34% for T1, and 12.72% for T2, but increased at the higher T 25° C to 18.18% for control, 15.32% for T2, and 26.66% for T1 (27). However, eggplants are sensitive to cooling, especially when stored at temperatures below 12° C with rapid physiological disturbances producing surface pitting, bronzing, burning, browning, and other symptoms of chilling (23). The recommended storage temperature for eggplant is 10 - 12° C and RH 90 - 95%. The weight loss was 0.12% in day 1 which was influenced by storage at 15.5° C and 92% RH. The lower temperature caused chilling injury (12) in eggplants, with chill symptoms appearing after 12 days for stored at 7.5° C, and within 6 days at 5° C (18). The eggplant crop was stored for seven days at a 15° C and RH of 90%, for four days at 30° C and five days at 20 - 25° C (14). The WLP increased under ambient conditions compared to low temperatures of 12 - 15.5° C and 96% RH for vegetable storage under evaporative cooling conditions (25). The average WL was 0.84, 1.2, and 1.64% on storage days 8, 14, and 20, respectively, for the control eggplants, while the average weight loss decreased over the storage days when the samples were treated with hot water at 40° C. However, weight loss increased for eggplants treated with hot water at 45° C. Finally, increasing the water temperature to 53° C decreased WLP at storage time.

On the other hand, eggplant WLP decreased in samples treated with UV at all dosages (24). Fresh eggplant, like other vegetables, has short storage time due to the significant amount of tissue breakdown and increased metabolism. Enzymatic browning and tissue softening occur rapidly, leading to significant declines in both sensory and nutritional quality. However, the shelf life of eggplants under optimal conditions is approximately 10 days (13). In general, ripe eggplants have short storage of 3 days at ambient temperatures, and physiological disturbances can lead to peel shrinkage and moisture loss, which negatively affect the market value and quality of eggplants. Therefore, vegetables should be kept fresh via different technologies such as cold storage (10).

Packaging is designed to prolong the shelf-life of food products, thus making them available for extra days, attractive to buyers, and affordable (5). Prolonged shelf life, better quality, and assured safety are the hallmarks of packaging films for addressing post-harvest losses of FandV (17). Packaging is an essential element in the food manufacturing process, as it safeguards fresh agricultural products and facilitates their seamless transportation from producers to consumers (22). It plays a very important role in terms of protecting crops from dust, preventing microbial contamination from the nearby environment and helping to preserve their freshness (26).

The quality of the eggplants was maintained when stored at a controlled temperature of 10° C (6), while the optimal storage temperatures were 10 - 12° C and 90 - 95% RH because eggplants decay quickly under ambient conditions (8). Harvest time during the year impacts post-harvest storage duration (7). The aim of this study was to extend the shelf life of eggplants by at least one week, taking into consideration weight-loss percentage (WLP), temperature (°C), relative humidity (RH%), and shelf-life days (SLD).

Materials and Methods

For this study, the box used for eggplant storage was designed and tested by (19), and Arduino systems were used to maintain temperatures and relative humidity. Humidity in the range of 90-95% was controlled, and the characteristics were evaluated according to two criteria: first, 12% weight loss and second, visual quality, which was dependent on color and firmness. As such, the sample was not evaluated when one of the characteristics came first (2). While various studies have been conducted on extending the shelf life of eggplants, this study’s focus was on prolonging it by one week using evaporative cooling. The samples were was measured daily using a hedonic scale from 1 to 9. This scale offers more accurate results. Weight loss was recorded using a digital scale, type SF-400. The weights of the eggplant samples were measured daily during storage to determine the WLP using equation (1).

$$\text{WLP} = \frac{\text{first weigh– last weight}}{\text{first weight}} \text{ X } 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

An air cooler sized 2000 ft^3/s was used in the field experiment as shown in Table 1 and Figure 1.

Table 1: Specifications of the evaporative cooler used in the experiment.

Type/Make	Pak Khazar, Iran
Power	**¼ Hp**
Tank (L)	**22**
Motor speed1(rpm)	**1290**
Motor speed2 (rpm)	**1320**

The dream eggplant crop from Seminis Thailand was used. The experiment was based on a randomized complete block design (RCBD) using three replications and the least significant difference (LSD) test with a probability of 0.05. Tukey's test was used to show the difference between the means.

Experimental Design:

Three factors were tested in this study.

1. The first used air speed as the main factor and had two levels:
   A. Initial airspeed of 3.6 m/s (S1), and
   B. Second airspeed of 4.3 m/s (S2).
2. The second factor involved packaging and non-packaging:
   A. Packing the eggplant crop in a plastic bag (P), and
   B. Without packaging (NP).
3. Finally, cooling and non-cooling methods were used.

The data was analysed using three-way ANOVA using orginPro2018 and SAS9.4. The samples were placed in a wooden box and wrapped with plastic or left unwrapped (Figure 2). The duration of storage of the crop was noted until the WL reached 12%.

(a) (b)

Figure 1: Storage of the eggplant samples: (a) evaporative cooler with wooden box; (b) transparent, perforated polyethylene bag.

Figure 2: Wooden box containing the eggplant crop.

Results and Discussion

Table 2 shows the overall ANOVA of the three factors and their influence on shelf-life days. The shelf-life days (SLD) significantly differed for the storage, packaging, and air speed data. At the 0.05 level, the population means for A, B, and C were significantly different. Also, at the same level, the population means for A*B, A*C, B*C, and A*B*C were significantly different.

Table 2: Overall ANOVA of the three factors and their influence on shelf-life days.

	Df	Sum of squares	Mean square	F Value	P Value
A	1	117.04167	117.04167	1404.5	0
B	1	18.375	18.375	220.5	8.88967E-11
C	1	30.375	30.375	364.5	1.95666E-12
A*B	1	5.04167	5.04167	60.5	7.9714E-7
A*C	1	40.04167	40.04167	480.5	2.31815E-13
B*C	1	3.375	3.375	40.5	9.39421E-8
A*B*C	1	7.04167	7.04167	84.5	8.74818E-8
Model	7 16	221.29167 1.33333	31.6131 0.8333	379.35714 0	2.22045E-16
Error					0
Corrected Total	23	222.625	0	0	0

A= cooling and non-cooling; B= P vs NP; and C= S1 vs S2.

Table 3: Overall ANOVA of the three factors and their influence on average shelf-life days.

			N	Mean	SD	SEM	Variance	Missing	Non-missing
CE	**P**	**S1**	3	11	0	0	0	0	3
		S2	3	8	0	0	0	0	3
	NP	**S1**	3	12	0	0	0	0	3
		S2	3	5.3333	0.577735	0.3333	0.3333	0	3
NCE	**P**	**S1**	3	6	0	0	0	0	3
		S2	3	6	0	0	0	0	3
	NP	**S1**	3	3	0	0	0	0	3
		S2	3	3.6667	0.577735	0.3333	0.3333	0	3

The three-way interactions for all factors were significantly different, except for NCE S1 vs NCP S2, which means that packaging without cooling did not make any difference.

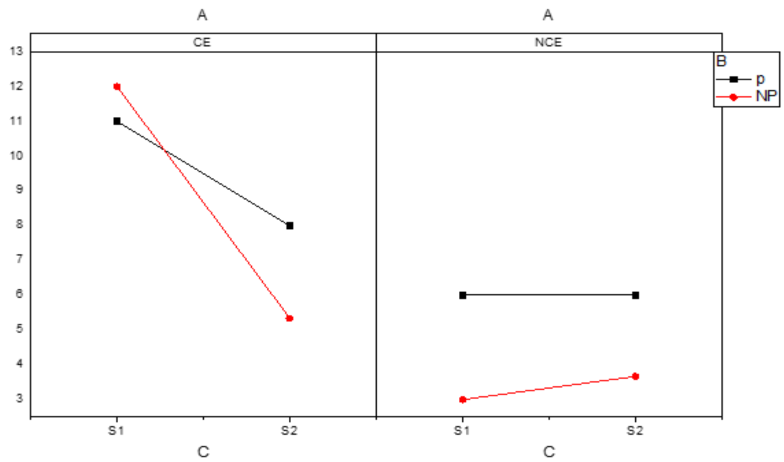

Figure 3: Three-way integration between the factors CE vs NCE, P vs NP, and S1 vs S2.

The results shown that evaporative cooling together with airspeed and packaging have a significant difference on the shelf-life days and WLP of the eggplants.

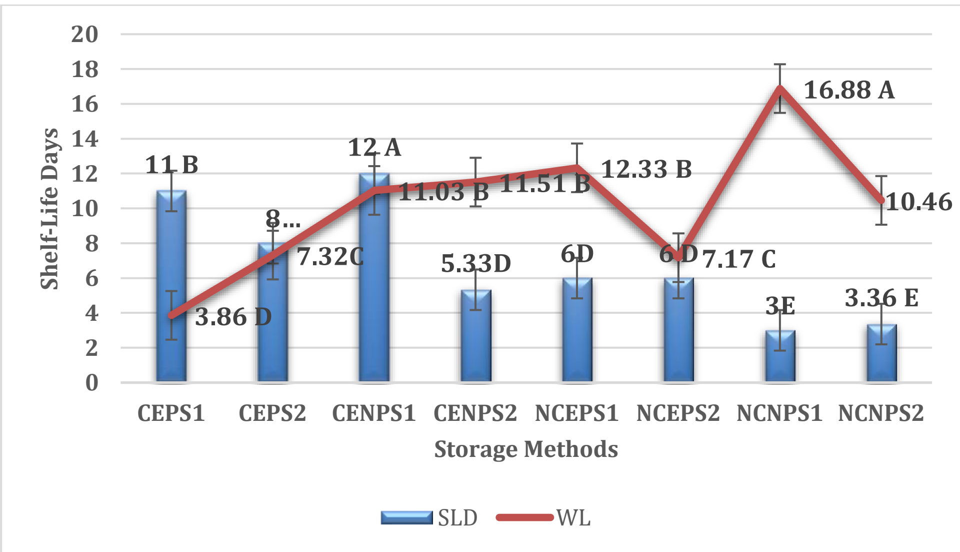

Figure 4: Relationship between SLD and WLP for all storage conditions.

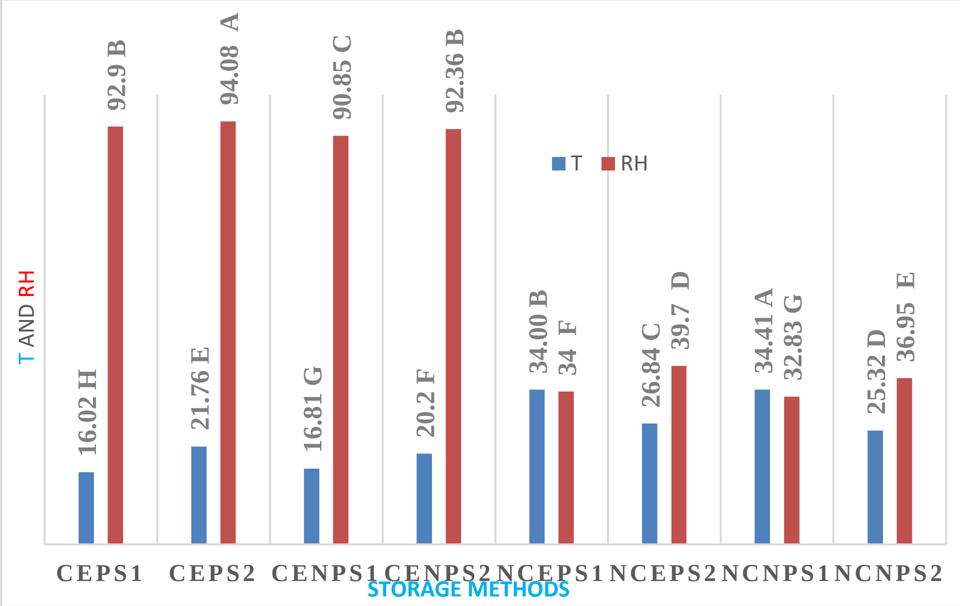

Figure 5: Average temperature and relative humidity during each storage experiment.

Figure 4 shows that the average SLD for CPS1 was 11 days, while the lowest average WL was 3.86% at 16.02° C and the average relative humidity was 92.9% (Figure 5). For CPS2, the average SLD was 8 days, with averages for temperature, relative humidity, and WL at 21.76° C, 94.08%, and 7.23%, respectively.

The average SLD for CNPS1 was 12 days, while the respective average temperature, relative humidity, and WL were 16.81° C, 90.85%, and 11.03%.

The average SLD for CNPS2 was 5.33 days, and the averages for temperature, relative humidity, and WL were 20.20° C, 92.36%, and 11.03%, respectively. The average SLD for NCPS1 was 6 days, while the respective average temperature, relative humidity, and WL were 34° C, 34%, and 11.51%.

The average SLD for NCPS2 was 6 days, with the average temperature, relative humidity, and WL at 26.84° C, 39.70%, and 7.17%, respectively. The average SLD of NCNPS1 was 3 days and were 34.41° C, 32.83%, and 16.88% for temperature, relative humidity, and WL, respectively. The average SLD of NCNPS2 was 3.66 days, and the averages for temperature, relative humidity, and WL were 25.32° C, 36.95%, and 10.46%, respectively.

A simple evaporative cooling system for extending the shelf life of eggplants for 12 days was used to address this research question; furthermore, packaging was shown to have a significant role in reducing weight loss. These results are consistent with those obtained by (13) who confirmed that packaging maintained the quality (26). The results derived in this research exceeded that of (27) who recorded weight loss at 7.75% when stored for 10 days at 10° C. This research resulted in lower weight loss at 3.36% on day 11 during cold storage with S1 packaging. This may be attributed to the use of evaporative cooling which raised the relative humidity and reduced temperatures (3).

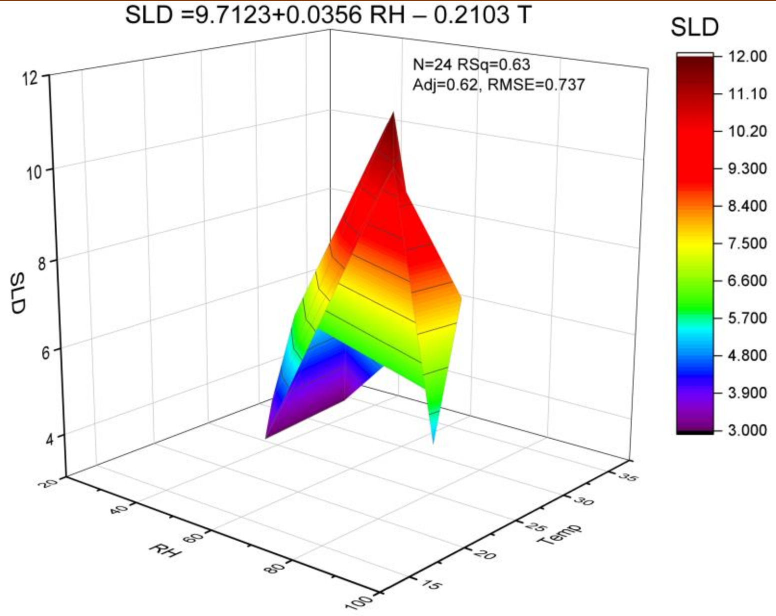

Figure 6: Eggplant shelf-life days associated with temperature and RH.

The 3D model in Figure 6 shows the relationship between temperature, relative humidity, and shelf-life days. The coefficient of temperature is lower than for relative humidity, which means that it is more significant than RH under the conditions of this experiment. However, the RH was controlled when using evaporative cooling.

Shelf-life days (SLD) were significantly affected by storage conditions (cooling vs non-cooling), packaging (packaging vs non-packaging), and air speeds (S1 vs S2). The longest average SLD of 12 days was achieved using cooling with non-packaging at the lower air speed (CNPS1), followed by 11 days for cooling with packaging at the lower air speed (CEPS1). Non-cooling conditions resulted in much shorter SLD, with the lowest being three days for non-cooling with non-packaging at both air speeds (NCNPS1 and NCNPS2).

Weight Loss Percentage (WLP) was lowest at 3.86% for CEPS1, which had the second longest SLD of 11 days. WLP was highest at 16.88% for NCNPS1, which had one of the shortest SLD at 3 days. In general, cooling and packaging reduce WLP compared to non-cooling and non-packaging conditions.

Temperature and Relative Humidity: Cooling conditions maintained lower temperatures of 16 - 22° C and higher relative humidity (90 - 94%) compared to non-cooling (25 - 34° C and 33 - 40% RH). The combination of lower temperature and higher humidity in the cooling treatments likely contributed to the extended SLD and lower WLP.

In summary, the results demonstrate that evaporative cooling, especially when combined with packaging, can significantly extend the shelf life of eggplants by maintaining lower temperatures and higher humidity, and reduces weight loss compared to non-cooling storage conditions. The lower air speed (S1) also appeared to be more effective than the higher speed (S2) in most cases. These findings highlight the potential of evaporative cooling system to address post-harvest losses and improve the storage life of eggplants and other perishable crops.

Further studies are needed to enhance the understanding and application of evaporative cooling and packaging methods for extending the shelf life of eggplants and other perishable crops. They should study various other fruits and vegetables, and the optimization of packaging materials and their interaction with cooling systems to provide insights into how different combinations affect weight loss and shelf life.

Conclusions

Evaporative cooling has been shown to benefit the post-harvest conditions of eggplants by maintaining lower temperatures and higher relative humidity compared to ambient conditions. Eggplants stored in evaporative cooling with packaging exhibited better post-harvest quality, with reduce weight loss and extended shelf life compared to those stored at evaporative cooling without packaging and those stored at ambient conditions. Packaging materials such as low-density polyethylene bags combined with evaporative cooling, have been shown to maintain the physio-chemical quality and shelf-life duration of eggplants.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

Author 1: methodology, writing—original draft preparation; Author 2: data analysis writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Institutional Review Board Statement:

The study was conducted in accordance with the protocol authorized by the Ministry of Higher Education, Iraq Republic.

Informed Consent Statement:

No Informed Consent Statement.

Data Availability Statement:

No data availability statement.

Conflicts of Interest:

The authors declare no conflict of interest.

Acknowledgments:

The authors are thankful for the help of the Department of Farm Machinery and Equipment, College of Agricultural Engineering Sciences, University of Baghdad, Iraq. We would also like to thank Mr. Ahmad Adana Najam for his valuable help and technical assistance in conducting this research.

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