

Effect of Preservation Methods and Storage Duration on the Microbiological Quality and Economic Feasibility of Giza 6 Onion (*Allium cepa* L.)

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تأثير طرق الحفظ ومدة التخزين على الجودة الميكروبيولوجية والجدوى الاقتصادية للبصل صنف جيزة 6 - *Allium cepa* L.

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Abstract

This study evaluated the effects of four preservation and treatment methods—traditional storage, refrigerated storage, natural drying, and oven drying—during storage periods of 2, 4, and 6 months on the microbiological quality of Giza 6 onion (*Allium cepa* L.), together with a simplified economic evaluation of the four treatments. Microbiological indicators included total microbial count, coliform bacteria, *Escherichia coli*, and yeasts and moulds, with results expressed as CFU/g. Microbial load increased markedly under traditional storage after six months, reaching 5×10^3 CFU/g for total count, 1.6×10^3 CFU/g for coliforms, and 2×10^3 CFU/g for yeasts and moulds. Refrigerated storage was more effective than traditional storage in limiting growth during the early and intermediate stages, whereas natural drying maintained relatively low levels. Oven drying recorded the lowest microbial load and the most stable pattern; total count remained at 100 CFU/g or below the counting limit, coliforms and *E. coli* were not detected, and yeasts and moulds remained below 100 CFU/g. *E. coli* was not detected in any treatment. Because some results were constrained by counting/detection limits (<10 and <100) and others were recorded as “not detected,” the microbiological data were presented descriptively without converting them to zero or directly subjecting them to numerical ANOVA. Economically, natural drying achieved the highest net profit (250 Libyan dinars) and the highest return on cost (500%) under the prices and costs used, whereas refrigerated storage retained the greatest quantity of marketable fresh product. The results indicate that the preferred preservation method depends on the objective: oven drying was best for microbiological stability, natural drying for calculated profitability, and refrigeration for maintaining the quantity of fresh product.

Keywords: onion; *Allium cepa* L.; microbiological quality; storage; drying; coliforms; *E. coli*; yeasts and moulds.

الملخص

هدفت الدراسة إلى تقييم تأثير أربع طرق للحفظ والمعاملة - التخزين التقليدي، والتخزين المبرد، والتجفيف الطبيعي، والتجفيف بالفرن - خلال مدد تخزين بلغت 2 و4 و6 أشهر على الجودة الميكروبيولوجية للبصل (*Allium cepa* L.). صنف جيزة 6، مع إجراء تقييم اقتصادي مبسط للمعاملات الأربع. شملت المؤشرات الميكروبية العدد الكلي للأحياء الدقيقة، وبكتيريا القولونيات، و*Escherichia coli*، والخمائر والأعفان، وُعبرت النتائج بوحدة CFU/g. ارتفع الحمل الميكروبي في التخزين التقليدي بوضوح بعد ستة أشهر، إذ بلغ العدد الكلي 5×10^3 CFU/g، والقولونيات 1.6×10^3 CFU/g، والخمائر والأعفان 2×10^3 CFU/g. وكان التخزين المبرد أفضل من التقليدي في الحد من النمو خلال المراحل الأولى والمتوسطة، في حين حافظ التجفيف الطبيعي على مستويات منخفضة نسبياً. وسجل التجفيف بالفرن أدنى حمل ميكروبي وأكثر نمط ثباتاً؛ إذ بقي العدد الكلي عند 100 CFU/g أو أقل من حد العد، ولم تُكتشف القولونيات أو *E. coli*، وبقيت الخمائر والأعفان أقل من 100 CFU/g. ولم تُكتشف *E. coli* في جميع معاملات الدراسة. وبسبب وجود نتائج مقيدة بحدود العد/الكشف (أقل من 10 وأقل من 100) ونتائج «غير مكتشف»، غُرِضت البيانات الميكروبية وصفيًا دون تحويلها إلى صفر أو إخضاعها مباشرة لتحليل ANOVA عددي. اقتصاديًا، حقق التجفيف الطبيعي أعلى صافي ربح (250 دينارًا) وأعلى معدل عائد على التكلفة (500%) ضمن الأسعار والتكاليف المستخدمة، بينما حافظ التبريد على أعلى كمية قابلة للبيع من المنتج الطازج. وتشير النتائج إلى اختلاف أفضل طريقة الحفظ باختلاف الهدف؛ فالتجفيف بالفرن كان الأفضل من حيث الثبات الميكروبي، والتجفيف الطبيعي من حيث الربحية المحسوبة، والتبريد من حيث المحافظة على الكمية الطازجة.

الكلمات المفتاحية: البصل؛ *Allium cepa* L.؛ الجودة الميكروبيولوجية؛ التخزين؛ التجفيف؛ القولونيات؛ *E. coli*؛ الخمائر الأعفان.

1. Introduction

Onion (*Allium cepa* L.) is a widely consumed vegetable crop, and its storability is affected by postharvest conditions, particularly temperature, humidity, bulb integrity, and handling practices. Mahmud and Monjil (2015) reported that unsuitable storage conditions are associated with increased onion diseases and bulb deterioration during storage. Kiran et al. (2024) emphasized that maintaining onion quality and extending storage life depend greatly on appropriate postharvest technologies and storage conditions, while Suravi et al. (2024) indicated that high temperature and humidity during storage increase postharvest losses and promote deterioration and rotting. Therefore, controlling preservation conditions is essential for maintaining bulb quality and reducing losses during storage.

Microbial load is an important indicator for evaluating the stability of onion and onion products during storage. Common indicators include total microbial count, coliforms, yeasts and moulds, together with detection of *Escherichia coli*. Firstenberg et al. (1974) showed that pretreatments and the drying process itself can clearly affect the microbial quality of dehydrated onion. Kadam et al. (2009) likewise demonstrated that pretreatments and drying method influence bacterial and fungal loads of onion slices during storage. Savitha et al. (2022) reviewed bacterial and fungal contamination as an important challenge in onion and dried onion products and emphasized that the choice of decontamination or microbial-reduction method should consider product characteristics and processing and storage conditions.

Drying temperature is one of the factors influencing the microbiological stability of dried products. García et al. (2010) found that drying temperature strongly affected microbial survival in dried green onion and that stability indicators improved at 70°C. Rahmani and Khama (2020) also examined changes in yeast and mould counts during drying of yellow onion. Savitha et al. (2022) noted that drying is widely used to extend onion shelf life, while microbial contamination still requires control throughout processing and storage.

Accordingly, the present study aimed to compare microbiological changes in Giza 6 onion under traditional storage, refrigeration, natural drying, and oven drying over six months; to identify the most effective method for limiting microbial load as storage progressed; and to conduct a simplified comparison of the economic feasibility of the four treatments.

2. Materials and Methods

2.1 Plant Material and Treatment Design

Dry yellow onion cultivar Giza 6 was used. A total of 120 kg was collected from a farm in Al-Hira, Libya, on 13/6/2023. A random sample was taken before applying the treatments for initial examinations (T₀). The remaining quantity was divided into four treatments at approximately 30 kg per treatment, with three replicates per treatment (approximately 10 kg per replicate). Treatments comprised traditional storage in a well-ventilated place, refrigerated storage at 4°C and approximately 65% relative humidity, natural drying, and oven drying. For natural drying, bulbs were peeled, washed, manually cut into thin slices, and 30 g of salt was added. The slices were spread on flat boards and exposed to direct sunlight for approximately 4–9 h/day for 3–5 days at an ambient temperature of about 34°C until dry. For oven drying, similarly prepared slices were treated with 30 g of salt, placed on trays, and dried in a BINDER electric drying oven at 70°C for 72 h. Dried samples were then stored in plastic containers at room temperature. Microbiological examinations were performed before treatment (T₀) and after 2, 4, and 6 months.

2.2 Preparation of Samples for Microbiological Examination

The initial suspension for each sample was prepared by adding 10 g of onion to 90 mL of sterile peptone water, followed by homogenization and preparation of appropriate decimal dilutions under aseptic conditions. Suitable dilutions were used for plating and enumeration, and final results were expressed as colony-forming units per gram (CFU/g).

2.3 Total Microbial Count

Plate Count Agar (PCA) was used to determine the total microbial count. A 0.1-mL aliquot of the appropriate dilution was inoculated onto Petri dishes, which were incubated at 37°C for 48 h. Colonies were counted on suitable plates, and the count was calculated as CFU/g according to the dilution used.

2.4 Coliforms and E. coli

Coliform bacteria were estimated using the selective medium employed in the laboratory examination, and results were recorded as CFU/g. The presence or absence of E. coli in each sample was recorded according to the original laboratory examination. To avoid adding details that were not documented in the experimental record, this step is described only according to the plating and detection procedures actually recorded in the study.

2.5 Yeasts and Moulds

For enumeration of yeasts and moulds, 0.1 mL of the appropriate dilution was spread on the designated medium containing glucose and chloramphenicol. Plates were incubated at 25°C for 5–7 days before counting. Results were expressed as CFU/g, based on the examination procedures recorded in the study and on Al-Hassanein et al. (2020) for microbiological characterization of dried onion slices.

2.6 Data Handling

The original microbiological records contained numerical measurements together with results constrained by counting or detection limits, such as <10 and <100 CFU/g, and results recorded as “not detected.” Values below the counting/detection limit are left-censored data because the true value lies below the specified limit and is not necessarily equal to the limit itself. Therefore, the original replicate records were used as the reference for presenting the results. Values reported as <10 or <100 were not converted to 10 or 100 for calculating means, standard deviations, or conventional analysis of variance (ANOVA), and “not detected” results were not converted to numerical zeros. This avoids introducing hypothetical measurements that could affect means, variance, and statistical inference. Accordingly, the microbiological results were presented descriptively while preserving the original laboratory-record format and comparing trends among preservation methods and storage durations. This conservative approach is consistent with methodological recommendations for handling microbial data censored by detection or quantification limits (Canales et al., 2018; Bahk & Lee, 2021).

3. Results

Table 1 presents the recorded microbiological results according to preservation method and storage duration (CFU/g), while retaining counting/detection limits as reported in the original records.

Treatment	Duration (months)	Total count	Coliforms	E. coli	Yeasts & moulds
Before treatments (T0)	0	70 ± 10	0	0	<10
Traditional storage	2	<100; 7×10 ² ; 7×10 ²	1.0×10 ²	Not detected	1.3×10 ²
Traditional storage	4	<100	1.2×10 ³	Not detected	1.2×10 ²
Traditional storage	6	5×10 ³	1.6×10 ³	Not detected	2×10 ³
Refrigerated storage	2	5×10 ²	Not detected	Not detected	1.0×10 ²
Refrigerated storage	4	6×10 ² ; 7×10 ² ; 7×10 ²	Not detected	Not detected	1.0×10 ²
Refrigerated storage	6	9.1×10 ²	6×10 ²	Not detected	7×10 ²
Natural drying	2	<100	Not detected	Not detected	2.0×10 ²
Natural drying	4	<100	Not detected	Not detected	3.0×10 ²
Natural drying	6	3×10 ²	Not detected	Not detected	<100
Oven drying	2	100	Not detected	Not detected	<100
Oven drying	4	<100	Not detected	Not detected	<100
Oven drying	6	<100	Not detected	Not detected	<100

Note: “<10” and “<100” indicate that the result was below the counting/detection limit; they do not mean exactly 10 or 100, nor zero. “Not detected” indicates that no detectable growth was recorded by the method used. These limits were therefore not used as substitute numerical values for calculating means or for ANOVA.

3.1 Total Microbial Count

Before treatment, the mean total count was 70 CFU/g with a standard deviation of 10 CFU/g. Under traditional storage, a clear increase occurred with longer storage, reaching 5×10^3 CFU/g after six months. Under refrigeration, the count was 5×10^2 after two months, approximately $6-7 \times 10^2$ after four months, and 9.1×10^2 CFU/g after six months. Under natural drying, the total count remained below 100 CFU/g at months two and four and reached 3×10^2 CFU/g at month six. Oven drying showed the most stable pattern, with 100 CFU/g after two months and <100 CFU/g after four and six months.

3.2 Coliforms and E. coli

Coliforms appeared under traditional storage from month two at 1.0×10^2 CFU/g and increased to 1.2×10^3 and 1.6×10^3 CFU/g after four and six months, respectively. Coliforms were not detected under refrigeration during months two and four but were recorded at 6×10^2 CFU/g in month six. Coliforms were not detected under natural or oven drying throughout the study. E. coli was not detected in any preservation treatment or storage duration. This is a positive finding for this specific indicator, but it does not by itself establish overall microbiological safety.

3.3 Yeasts and Moulds

Traditional storage recorded 1.3×10^2 and 1.2×10^2 CFU/g after two and four months, respectively, increasing to 2×10^3 CFU/g after six months. Under refrigeration, the value remained at 1.0×10^2 CFU/g in months two and four and increased to 7×10^2 CFU/g in month six. Natural drying recorded 2.0×10^2 and 3.0×10^2 CFU/g at months two and four, respectively, before decreasing to <100 CFU/g at month six. Oven drying remained below 100 CFU/g throughout the three storage periods.

4. Discussion

Escherichia coli was not detected in onion samples under any of the four preservation methods throughout the six-month storage period. This indicates non-detection within the limits and method used and does not by itself mean complete absence of all forms of microbial contamination. The lack of detection in dried products agrees with Kadam et al. (2009), who reported no E. coli growth in the stored dehydrated onion slices they studied. Nevertheless, this finding should be interpreted specifically in relation to the indicator and detection method used in the present study.

Traditional storage showed the clearest increase in microbial load as storage duration increased. By the end of month six, total count reached 5×10^3 CFU/g, coliforms 1.6×10^3 CFU/g, and yeasts and moulds 2×10^3 CFU/g. This trend may be explained by the less controlled temperature, humidity, and handling conditions of traditional storage, which can provide more favorable conditions for continued microbial deterioration than more controlled preservation methods. This interpretation agrees with Mahmud and Monjil (2015), who linked onion diseases during storage to storage conditions, and Suravi et al. (2024), who emphasized the importance of temperature and humidity in postharvest losses and onion quality deterioration.

Refrigerated storage limited microbial growth during most of the storage period but did not completely prevent it by month six. Coliforms were not detected during months two and four but were recorded at 6×10^2 CFU/g after six months; yeasts and moulds increased to 7×10^2 CFU/g and total count to 9.1×10^2 CFU/g. This indicates that refrigeration considerably slows microbial deterioration but does not sterilize the product. Ji et al. (2018) showed that fungal diseases can remain problematic in onion during low-temperature storage, supporting the need to combine refrigeration with sound bulbs, hygiene, and control of storage conditions.

Under natural drying, coliforms were not detected throughout storage, and total count remained lower than under traditional and refrigerated storage: <100 CFU/g at months two and four and 3×10^2 CFU/g at month six. Yeasts and moulds were 2×10^2 and 3×10^2 CFU/g after two and four months, respectively, and <100 CFU/g after six months. The large reduction in moisture following drying likely contributed to conditions less favorable for microbial growth. This agrees with Kadam et al. (2009), who recorded low microbial loads in dehydrated onion slices during storage, and with Rahmani and Khama (2020), who linked onion drying and reduced moisture content with lower yeast and mould counts, while emphasizing the need to control drying and storage conditions.

Oven drying achieved the best microbiological stability pattern in this study. Neither coliforms nor E. coli were detected throughout storage, yeasts and moulds remained below 100 CFU/g, and total count was 100 CFU/g after two months and <100 CFU/g after four and six months. This may be explained by the combined effects of heat treatment and the marked reduction in moisture, which make the product less favorable for continued microbial growth. García et al. (2010) found that drying temperature strongly affected microbial survival in dried onion and

that stability indicators improved at 70°C. Rahmani and Khama (2020) also reported an encouraging reduction in moulds after oven drying, while Savitha et al. (2022) emphasized the importance of heat treatments and contamination-reduction technologies for improving the safety and microbiological stability of onion products. Overall, the findings support a trade-off between maintaining onion in a near-fresh form and achieving longer microbiological stability. Refrigeration retained a larger quantity of fresh product while relatively suppressing microbial growth, whereas drying—especially oven drying—provided a stronger barrier to growth over the study period. This general trend is consistent with Kiran et al. (2024) and Savitha et al. (2022), who emphasized selecting postharvest technology according to the preservation objective and product characteristics. Microbiological superiority should also be interpreted alongside chemical and nutritional findings because increasing drying intensity may improve microbiological stability while affecting some heat-sensitive nutritional components.

5. Conclusions

The descriptive results showed that the microbiological pattern of onion differed according to preservation method and storage duration. Traditional storage was most susceptible to increased microbial load when storage was extended to six months, whereas refrigeration limited this increase without completely preventing it. Natural drying clearly reduced microbial load, while oven drying was the most stable microbiologically throughout the six months. *E. coli* was not detected in any treatment by the method used, whereas coliforms appeared mainly under traditional storage and under refrigeration after six months. The results support the use of thermal drying when long-term microbiological stability is the priority, while taking its effects on nutritional attributes into account.

6. Economic Feasibility of Each Treatment

Because demand and market value differ between fresh and dried onion, a simplified economic evaluation of the four treatments was conducted using an initial quantity of 30 kg per treatment. The evaluation included treatment cost, quantity remaining after storage or drying, selling price, total revenue, and net profit. The calculations were prepared by the researchers. To improve comparison among alternatives, return on investment/cost (ROI) and the benefit-cost ratio (B/C) were also calculated.

6.1 Treatment Costs

Treatment	Purchase/preparation cost for 30 kg (LYD)	Treatment implementation cost (LYD)	Total cost (LYD)
T1 Traditional storage	29	6	35
T2 Refrigerated storage	35	10	45
T3 Natural drying	35	15	50
T4 Oven drying	35	15	50

The total treatment cost for 30 kg was 35 Libyan dinars for traditional storage, 45 dinars for refrigerated storage, and 50 dinars each for natural and oven drying. These values include the product purchase cost and treatment preparation/implementation costs according to the original records.

6.2 Remaining Quantity and Selling Price

Treatment	Remaining quantity from 30 kg	Selling price
T1 Traditional storage	9 kg	5 LYD/kg
T2 Refrigerated storage	27 kg	5 LYD/kg
T3 Natural drying	7.5 kg	4 LYD/100 g
T4 Oven drying	6 kg	4 LYD/100 g

Refrigerated storage retained the highest marketable quantity, with 27 kg remaining from the initial 30 kg (90% of initial weight), compared with 9 kg under traditional storage. Natural and oven drying yielded 7.5 and 6 kg, respectively. This reduction should not be described entirely as “economic loss,” because a substantial part represents water intentionally removed during drying; it therefore reflects drying/conversion yield rather than deterioration in the conventional sense.

6.3 Revenue, Net Profit, and Economic Efficiency Indicators

Treatment	Total cost (LYD)	Revenue (LYD)	Net profit (LYD)	ROI (%)	B/C	Profit margin (%)
T1 Traditional storage	35	45	10	28.57	1.29	22.22
T2 Refrigerated storage	45	135	90	200.00	3.00	66.67
T3 Natural drying	50	300	250	500.00	6.00	83.33
T4 Oven drying	50	240	190	380.00	4.80	79.17

The calculations showed that natural drying achieved the highest revenue (300 Libyan dinars) and the highest net profit (250 dinars), followed by oven drying with a net profit of 190 dinars, refrigerated storage with 90 dinars, and traditional storage with 10 dinars. ROI was approximately 500% for natural drying, 380% for oven drying, 200% for refrigerated storage, and 28.57% for traditional storage. The B/C ratios were 6.00, 4.80, 3.00, and 1.29, respectively. Under the prices and quantities assumed in the study, natural drying was the most profitable alternative.

6.4 Economic Interpretation

The results reveal an important distinction between “preserving quantity” and “maximizing value.” Refrigerated storage was best for maintaining marketable weight, retaining about 90% of the initial quantity and achieving a good economic return at a moderate cost. Natural drying reduced final product weight because of water removal but greatly increased market value per unit weight and therefore produced the highest net profit. Oven drying ranked second economically; although its direct cost was equal to that of natural drying in the present calculations, its mass yield was lower (6 kg versus 7.5 kg), reducing final revenue to 240 dinars. This interpretation is consistent with Suravi et al. (2024), who discussed the effects of postharvest losses on onion quality, marketability, and economic return, and with Savitha et al. (2022), who noted that drying is used to extend shelf life and facilitate handling of dried onion products, with operational and economic considerations influencing the choice of processing technology.

The choice of preservation method therefore depends on the marketing objective. Refrigeration is suitable when the priority is selling onion fresh and retaining the largest possible quantity, whereas natural drying appears more attractive under the prices used in this study when there is a market able to absorb dried onion at 4 Libyan dinars per 100 g. This conclusion is specific to the cost, quantity, and price data recorded in the experiment and should not be generalized to other production conditions or markets.

Nevertheless, these results represent partial treatment-level feasibility rather than a complete financial investment study. The available data do not include capital costs of equipment, actual electricity consumption, labor, packaging, transport, maintenance, price fluctuations, or opportunity cost. Therefore, the calculated rates of return should not be generalized beyond the prices and costs used in this experiment.

7. Integrated Conclusion

When the microbiological and economic results are considered together, natural drying emerges as the best treatment in terms of net profit under the present calculations, whereas oven drying achieved the best microbiological stability but ranked second economically. Refrigerated storage provided the best preservation of fresh quantity, with good profit and better microbiological stability than traditional storage during most of the study period. Thus, no single “best” method can be identified from one indicator alone: natural drying is superior in economic return, oven drying in microbiological control, and refrigeration in preservation of fresh quantity. This integrated assessment provides a practical basis for selecting a preservation strategy according to the marketing objective and storage period.

8. Study Limitations

The present microbiological comparison is based on raw records containing quantitative measurements, counting/detection limits, and “not detected” results. Therefore, means that could result from replacing

measurement limits with fixed values were not adopted, and significant differences were not inferred using conventional ANOVA for these data. This is a methodological limitation that should be considered when interpreting apparent differences among treatments (Canales et al., 2018; Bahk & Lee, 2021). The economic evaluation is a partial treatment-level assessment based on the costs, quantities, and selling prices recorded in the study and does not represent a complete investment analysis, because separate details were unavailable for all energy, labor, maintenance, transport, packaging, and price-fluctuation costs. Profitability indicators should therefore be interpreted within the experimental conditions and prices used.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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