**Research Article:**

**COMPARATIVE EVALUATION OF PRESERVATION METHODS ON THE MICROBIOLOGICAL AND PROXIMATE INDICES OF ONIONS (*ALLIUM CEPA* L.)**

**Abstract**
Onions (*Allium cepa* L.) are among the most widely utilized vegetables globally known for both their culinary and nutritional attributes. Despite their importance, onions are highly perishable and susceptible to quality degradation under suboptimal storage conditions, particularly due to fluctuations in humidity and temperature. This study evaluated the impact of three preservation techniques such as salting, drying, and freezing on the nutritional profile and microbiological safety of onion samples during storage. Fresh onions were processed into raw, salted, dried (as onion powder), and frozen forms. Proximate analyses were conducted to assess moisture, protein, ash, fat, fibre, and carbohydrate levels before and after storage. Standard microbiological procedures were used to determine total viable counts, coliforms, yeasts, and moulds, while microbial species were identified via morphological and biochemical characterization. Results showed a marked reduction in moisture content in dried onions, which correlated with increased concentrations of protein and carbohydrates. Salting significantly suppressed microbial proliferation, including coliform and fungal populations. Although freezing preserved initial moisture levels, it was associated with increased fungal activity, likely due to intermittent thawing. The most frequently isolated microorganisms included *Pseudomonas* spp. and *Staphylococcus* spp., as well as *Penicillium*, *Rhizopus*, and *Aspergillus* species. Overall, salting and drying proved most effective in enhancing shelf life and maintaining product quality.

**Keywords:** Onion preservation, freezing, drying, salting, microbiological safety

**Introduction**

Onions (*Allium cepa* L.) rank among the most extensively cultivated and consumed vegetables worldwide, valued for their culinary adaptability and recognized health benefits. Often termed the "Kitchen Queen," onions are foundational to various global cuisines and play a significant role in agricultural economies through both local consumption and export trade (Bal et al., 2020). From a nutritional standpoint, onions offer a substantial supply of carbohydrates, protein, dietary fibre, and essential minerals, including calcium, phosphorus, and iron. Furthermore, they are a source of bioactive compounds such as quercetin, which has been linked to antioxidant, anti-inflammatory, lipid-lowering, and potential anticancer effects (Anand David, 2016).

Despite these attributes, onions are notably perishable, with post-harvest losses frequently resulting from microbial spoilage, sprouting, and dehydration during storage and transport (Kakade et al. 2023). These challenges often arise due to inadequate control of environmental conditions such as temperature and humidity, as well as mechanical damage during handling (Petropoulos, 2016). Such deterioration not only diminishes market value but also contributes to food insecurity and economic losses for producers (Madhu et al., 2020).

Preservation strategies like salting, drying, and freezing are commonly applied to extend the shelf life of agricultural products (Ahmad et al. 2021). However, limited comparative data exist regarding how these methods differentially influences the nutritional quality and microbiological stability of onions during storage. While some studies have explored these methods individually, few have provided systematic evaluations of their relative efficacy under controlled conditions. This study addresses this gap by comparing the effects of salting, drying, and freezing on the proximate composition and microbial characteristics of onion samples. The findings aim to inform best practices for onion preservation, contributing to reduced spoilage, improved storage outcomes, and enhanced food safety.

**2. Materials and Methods**

**2.1 Sample Preparation**

Fresh Allium cepa bulbs were sourced from a reputable local market to ensure uniformity and quality across samples. Upon delivery to the laboratory, bulbs were processed by rinsing thoroughly to eliminate dirt and surface impurities as shown in Figure 1. The outer layers were manually removed to reduce the risk of pesticide residues and environmental contaminants. Cleaned onions were divided into four groups based on different preservation methods: Raw Onion (RO), Frozen Onion (FO), Onion Powder (OP), and Salted Onion (SO).

**2.1.1 Raw Onion (RO)**

This group served as the untreated control and represented the fresh, unprocessed state. The onions were analyzed immediately for both proximate and microbiological parameters to establish baseline values.

 **Fresh Onion**

Sorting/Selection

Cleaning

 Peeling

 **Slicing**

Freezing (−18°C) Drying (60 °C) Salting 5% (w/w)

 Grinding Osmotic dehydration~25°C, 24h

Storage (−18°C) Storage (−18°C) Storage (−18°C) Storage (−18°C)

 **Raw Onion (RO) Frozen Onion (FO) Onion Powder(OP) Salted Onion (SO)**

**Figure 1: Preparation of Onion Samples**

**Source:** El-Hadidy et al. (2014); Koménan et al. (2020); Pruthi (1987).

**2.1.2 Frozen Onion (FO)**

The onions were peeled and sliced into uniform thin layers. They were stored at −18°C, following the method outlined by El-Hadidy et al. (2014). The samples were kept at this temperature throughout the storage period to mimic commercial freezing conditions.

**2.1.3 Onion Powder (OP)**

The onion rings were sliced and dehydrated in a hot-air oven set at 60 °C until they reached a constant weight, following Koménan et al. (2020). After dehydration, the samples were ground into a fine powder using a laboratory grinder. They were then stored in airtight containers at room temperature (~25°C) for further analysis.

**2.1.4 Salted Onion (SO)**

Salted onions were made by mixing sliced onions with 5% common salt (w/w), following Pruthi (1987). The mixture was left at room temperature (~25°C) for 24 hours to undergo osmotic dehydration. Afterward, the salted onions were placed in sterile containers and stored at 4°C.

The samples were stored under the following conditions: frozen onions (FO) at −18°C, salted onions (SO) at 4°C, and raw onions (RO) and onion powder (OP) at room temperature (~25°C). Proximate composition and microbial quality were checked weekly for three weeks.

**2.2 Methodology**

**2.2.1 Proximate Analysis**

Moisture content, crude protein, ash, fibre, and fat contents of the onion samples were analyzed using standard methods as prescribed by the Association of Official Analytical Chemists (AOAC, 2010). Carbohydrate content was calculated by difference. All measurements were performed in triplicate to ensure data accuracy and statistical reliability.

**2.2.2 Microbial Analysis**

Microbial load assessments included total viable count (TVC), coliform count, and yeast and mould enumeration. Sample homogenates were prepared by serial dilution in sterile peptone water, as outlined by Pitt and Hocking (2022). The pour plate technique was employed for microbial enumeration.

TVCs were cultured on Plate Count Agar (PCA), yeast and moulds on acidified Potato Dextrose Agar (PDA), and total coliforms on MacConkey Agar. Plates were incubated under appropriate conditions typically 24–48 hours for bacteria at 37°C and 3–5 days for fungi at 25°C before colony counting.

Identification of bacterial and fungal isolates was performed using standard biochemical and morphological techniques. These included Gram staining, catalase and oxidase tests, methyl red (MR), Voges-Proskauer (VP), and citrate utilization tests, in line with procedures from Adeniran et al. (2020). Fungal identification was based on colony morphology, hyphal structure, spore arrangement, and pigmentation, as described by standard mycological references.

**3. Results and Discussion**

**3.1 Proximate Composition of Onion Samples**

**3.1.1 Moisture Content**

As shown in Tables 1 and 2, the moisture content of onion samples varied considerably across preservation methods. Initial values ranged from 9.18% in onion powder (OP) to 87.32% in raw onion (RO). After storage, these values ranged from 9.04% to 85.14%, with the same trend observed. The markedly low moisture in OP underscores the efficiency of the drying process in water removal, a finding consistent with earlier reports by Paciulli et al. (2015) and Demissew et al. (2018). In contrast, frozen (FO) and salted onions (SO) retained relatively higher moisture levels (above 10%), potentially increasing the risk of microbial proliferation during storage, as noted by Hafez et al. (2019). Interestingly, the moisture levels in OP were slightly higher than values previously reported by Sorour and Mesery (2014), possibly due to variations in packaging materials or ambient humidity conditions.

**3.1.2 Protein Content**

Protein levels before storage ranged from 1.64% to 2.38%, with OP exhibiting the highest concentration, a result likely influenced by the reduction in moisture that concentrates the dry matter. After storage, protein content remained relatively stable, ranging from 1.58% to 2.29%. Minimal losses were observed in frozen and salted samples, which may result from protein denaturation, leaching during thawing, or salt-induced solubility reduction, aligning with findings from Al-Rubai et al. (2020) and Hafez et al. (2019). These changes were relatively minor, supporting Paciulli et al. (2015), who observed limited protein degradation from freezing. The increased protein concentration in dried samples mirrors established patterns in dehydrated vegetables (Wijewardana, 2016; Demissew et al., 2018).

**3.1.3 Ash Content**

Ash content, an indicator of total mineral presence, ranged from 2.39% to 2.93% before storage, and from 1.98% to 2.84% after storage. OP retained the highest ash values across both periods, a reflection of mineral concentration through moisture removal. Reductions in FO ash levels could be attributed to mineral leaching during thawing, as reported by Paciulli et al. (2015). The slight increase in ash content observed in SO may stem from salt–mineral interactions, with residual salt contributing to total mineral content (Rouphael et al., 2018). Despite these changes, overall mineral stability was maintained, although some variability could be due to degradation or leaching during storage (Gandotra et al., 2013).

**Table 1. Proximate composition of raw and processed onion samples at the beginning**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample | Moisture% | Protein% | NutrientsAsh% | Fat% | Fibre% | Carbohydrate% |
| RO | 87.32±0.11a | 2.12±0.03b | 2.46±0.03c | 0.94±0.04a | 1.74±0.04b | 5.48±0.01d |
| FO | 82.56±0.15c | 1.89±0.04c | 2.39±0.03c | 0.60±0.05b | 1.69±0.03c | 10.90±0.01c |
| OP | 9.18±0.01d | 2.38±0.03b | 2.93±0.02a | 0.36±0.10c | 3.23±0.05a | 81.95±0.02a |
| SO | 80.68±0.03b | 1.64±0.02a | 2.52±0.03b | 0.90±0.21a | 1.70±0.01b | 12.58±0.01b |

*Samples: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

*Nutrients: Moisture, Protein, Ash, Fat, Fibre, Carbohydrate*

*Values are mean±SD (n=3). Means with different superscript letters (a-c) in the same row are significantly different (p<0.05) by Duncan’s multiple range test.*

**Table 2 Proximate composition of raw and processed onion samples after storage**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sample** | Moisture% | Protein% | **Nutrients**Ash% | Fat% | Fibre% | Carbohydrate% |
| RO | 85.14±0.03a | 1.97±0.05c | 2.39±0.03c | 0.90±0.04a | 1.69±0.11b | 7.93±0.07c |
| FO | 79.94±0.11b | 1.80±0.04d | 1.98±0.03d | 0.53±0.02b | 1.69±0.06b | 14.06±0.04b |
| OP | 9.04±0.04d | 2.29±0.05b | 2.84±0.02a | 0.28±0.01c | 3.00±0.05a | 82.59±0.03a |
| SO | 78.22±0.10c | 1.58±0.04a | 2.65±0.01b | 0.82±0.05a | 1.63±0.10c | 15.14±0.03a |

*Samples: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

*Nutrients: Moisture, Protein, Ash, Fat, Fibre, Carbohydrate*

*Values are mean±SD (n=3). Means with different superscript letters (a-c) in the same row are significantly different (p<0.05) by Duncan’s multiple range test.*

**3.1.4 Fat Content**

Fat content across the onion samples was generally low, varying from 0.36% to 0.94% before storage and from 0.28% to 0.90% after storage. The impact of preservation on fat content was minimal, reflecting the relative stability of lipids in low-fat vegetables like onions. Minor reductions observed in FO and OP may be linked to oxidative degradation during storage or exposure to oxygen in packaging, consistent with findings by Al-Rubai et al. (2020). Salting had negligible influence on fat stability, in agreement with previous observations by Rouphael et al. (2018). Any increase post-storage was likely due to moisture loss concentrating residual lipids.

**3.1.5 Fibre Content**

Dietary fibre ranged from 1.69% to 3.23% before storage and from 1.63% to 3.00% post-storage. OP consistently exhibited the highest fibre content, a result of water removal concentrating indigestible solids, as noted by Agu et al. (2016) and Salve et al. (2020). Slight reductions in FO and SO fibre levels post-storage were observed, although these changes were not statistically significant. This aligns with findings that suggest insoluble fibre is largely resistant to common preservation techniques (Rouphael et al., 2018). Minor losses may be attributed to enzymatic degradation or oxidative activity during extended storage.

**3.1.6 Carbohydrate Content**

Carbohydrate content exhibited an inverse trend with moisture, ranging from 5.48% in RO to 81.95% in OP before storage, and increasing slightly post-storage to 7.93% in RO and 82.59% in OP. The substantial increase in OP carbohydrates reflects the effect of dehydration on concentrating starches, sugars, and fibre (Hervik and Svihus, 2019). In SO and FO samples, carbohydrate increases were marginal and likely a result of moisture loss rather than carbohydrate synthesis. A modest increase observed in RO may result from residual concentration or post-harvest sugar metabolism during ambient storage.

### ****3.2 Microbial Analysis****

Microbial analysis provides crucial insight into the hygienic quality and safety of preserved onion products. Figure 2 and Table 3 illustrate the total viable count (TVC) and coliform counts of both raw and processed onion samples under various preservation conditions. These microbiological indicators reflect the effectiveness of salting, drying, and freezing in limiting microbial proliferation during storage.

**3.2.1 Total Viable Count (TVC)**

The total viable count across preserved onion samples ranged from 1.8 × 10⁴ to 24.5 × 10⁴ CFU/g. At the beginning of the storage period, raw onions (RO) exhibited a relatively high TVC of 12.3 × 10⁴ CFU/g, which increased to 17.0 × 10⁴ CFU/g by the third week. This upward trend is expected, as the untreated samples retained high moisture content and were stored at ambient conditions, which favor microbial proliferation.

Onion powder (OP) presented the highest initial TVC among the processed samples, likely due to contamination introduced during the drying and milling stages. Equipment surfaces and environmental exposure during grinding may serve as contamination vectors, as observed by Nnenna (2020). Additionally, the increased surface area of powdered samples may facilitate microbial attachment and survival.

Despite a high initial count, the microbial load in OP did not escalate significantly during storage, indicating the long-term effectiveness of dehydration in limiting microbial activity. Frozen onions (FO) exhibited moderate microbial counts, potentially due to intermittent thawing and refreezing effects that encourage sporadic microbial growth. In contrast, salted onions (SO) consistently maintained low TVC values throughout storage. Both OP and SO demonstrated strong antimicrobial preservation effects, confirming findings by Debs Louka et al. (2013) and Salari et al. (2012), who reported that drying and salting substantially reduce microbial activity in spices and vegetables.

**3.2.2 Coliform Count**

Coliform bacteria are used as key indicators of sanitary quality in food products. As shown in Table 3, coliform counts in onion samples ranged from undetectable (0.00 × 10⁴ CFU/g) to 24.0 × 10⁴ CFU/g during the storage period. Raw onions showed a gradual increase in coliform levels, while onion powder maintained a relatively constant count, possibly due to environmental or processing contamination at the initial stages.

Notably, coliform bacteria were not detected in either frozen (FO) or salted onions (SO) during the entire study period. The absence of these organisms supports the efficacy of freezing and salting as microbial control measures. Freezing likely suppressed microbial metabolism by reducing enzymatic activity and water availability, whereas the hyperosmotic environment created by salt may have inhibited bacterial viability, a mechanism well-documented in food preservation literature (Agi et al., 2020).

Also, coliform counts observed in all samples remained within internationally accepted safety thresholds. The Codex Code of Hygienic Practice (FAO/WHO, 1995) recommends limits of 10³–10⁴ CFU/g for coliforms in dried spices. Even the higher counts in raw and powdered onions were below the maximum permissible levels, although they suggest reduced microbial quality compared to FO and SO. These results emphasize the microbial risks associated with storing raw onions and highlight the superior safety and shelf-stability achieved through salting and drying. The consistent absence of coliforms in FO and SO supports their use in safe onion preservation strategies, particularly under conditions where refrigeration and hygiene may be challenging.



*KEYS: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

*Values are mean±SD (n=3). Means with different superscript letters (a-c) in the same row are significantly different (p<0.05) by Duncan’s multiple range test.*

**Figure 2: Total Viable Count (cfu/g) of Raw and Processed Onion Samples during and after Storage**

**Table 3**: **Coliform bacteria Count (cfu/g) or Raw and Processed Onion Samples stored at different temperatures**

|  |  |  |  |
| --- | --- | --- | --- |
| Sample | Week 1 | Week 2 | Week 3 |
| RO | 12.5 x 104 | 13.3 x 104 | 13.0 x 104 |
| FO | 0.00 | 0.00 | 0.00 |
| OP | 24.0 x 104 | 24.5 x 104 | 24.0 x 104 |
| SO | 0.00 | 0.00 | 0.00 |

*RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

*Values are mean±SD (n=3). Means with different superscript letters (a-c) in the same row are significantly different (p<0.05) by Duncan’s multiple range test.*

### ****3.2.3 Yeast and Mould Counts****

Yeast and mould counts exhibited significant variability throughout the storage period, as shown in Figure 3. At the onset of storage, yeast and mould levels ranged from 1.6 × 10⁴ to 44.0 × 10⁴ CFU per gram across all samples. Over the three-week storage period, these counts decreased, with values dropping to between 1.2 × 10⁴ and 17.0 × 10⁴ CFU per gram by the end of the study. This reduction in yeast and mould growth underscores the effectiveness of the preservation methods like salting, freezing, and drying in controlling fungal proliferation.

The low incidence of yeast and mould growth in the preserved onion samples aligns with findings from previous research, which has reported that yeasts are relatively rare in spices and herbs (Adu-Gyamfi, 2007). Raw onions (RO), however, exhibited a higher initial yeast and mould count, with a slight increase in these levels during the storage period. This trend is consistent with expectations for untreated, moisture-rich foods stored at ambient temperatures, which provide a conducive environment for microbial growth.

Salted onions (SO) consistently showed the lowest levels of yeast and mould proliferation, suggesting that salting effectively reduces fungal growth. The osmotic pressure created by the salt likely impedes the ability of yeasts and moulds to thrive, highlighting salting's strong preservative qualities.

Notably, frozen onions (FO) exhibited the highest yeast and mould counts among the preserved treatments. Throughout the storage period, fungal growth in frozen onions continued to rise, in contrast to the decreasing levels observed in raw and dried samples. This increase can likely be attributed to the irregular freezing temperatures, which may have led to partial thawing and refreezing events. Such temperature fluctuations create conditions conducive to yeast and mould growth, as discussed by Salari et al. (2012), who found that fungal proliferation in frozen foods is often influenced by inconsistent temperature control, which promotes the survival and growth of yeasts and moulds.



*KEYS: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

*Values are mean±SD (n=3). Means with different superscript letters (a-c) in the same row are significantly different (p<0.05) by Duncan’s multiple range test.*

**Figure 3: Yeast and Mold Count (cfu/g) of raw and processed Onion sample stored at Different Temperatures**

**3.2.4 Fungal Isolate Characteristics**

The characteristics of fungal isolates recovered from the onion samples are detailed in Table 4. The fungal colonies were cultured on solid media and identified using a combination of morphological and biochemical tests. The identified fungal species included Penicillium, Aspergillus, and Rhizopus, all of which are commonly associated with food spoilage. These fungi typically thrive in environments characterized by high humidity and moderate temperatures.

Penicillium species were found in both raw and salted onions, exhibiting colonies with a greenish to blue-green coloration and a fuzzy texture. Aspergillus species were identified in onion powder, presenting black, fuzzy colonies with a cottony appearance. In the case of frozen onions, Rhizopus species were identified, characterized by pale white colonies with visible rhizoids and non-septate hyphae.

**Table 4: Characteristics and Biochemical Test of Fungal Isolates from Raw and Processed Onion samples during storage**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Characteristics/Tests** | **RO** | **FO** | **OP** | **SO** |
| **Appearance of Colonies on PDA plates****Reverse side appearance on PDA plate****Morphology** | Greenish to blue-green with a fuzzy texturePale yellow, smooth with dark pigmentSeptate hyphae, blue green conidia in three sets | Black, fuzzy colonies, cottony growthpale white, smooth with rhizoids visibleNon-septate hyphae, black, rhizoidal structures | Black powdery textureSulfur-yellow, smooth with separations between coloniesRadiated, black, septate hyphae with conidial heads | Greenish coloniesPale yellow, smooth with dark pigmentSeptate hyphae, blue-green phialides |
| **Cell Morphology** | Filamentous | Coenocytic | Filamentous | Filamentous |
| **Type of fertile hyphae** | Conidiophore | Sporangiospore | Conidiophore | Conidiophore |
|  |  |  |  |  |
| **Conidia/Sporangia position** | Exposed | Enclosed in sporangium | Exposed | Exposed |
| **Arrangement of Conidia** | Clustered | Clusters | Radiated from conidiophore | clustered |
| **Probable Identity** | *Penicillium* sp | *Rhizopus* sp | *Aspergillus* sp | *Penicillium* sp |

*KEYS: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion*

The moisture content of the frozen onions may have contributed to the growth of these fungi, especially in the presence of fluctuating storage temperatures. As indicated by the results, irregular freezing cycles may have caused partial thawing, creating pockets of moisture that serve as an ideal environment for fungal growth. These findings are consistent with the observations of Salari et al. (2012), who noted the potential for fungal contamination in frozen foods due to temperature fluctuations, further supporting the impact of inconsistent freezing on microbial growth.

**3.2.5 Bacterial Identification Result**

Table 5 presents the bacterial analysis results for both raw and processed onion samples. The bacterial colonies that grew on the media plates varied depending on the preservation method, with raw, frozen, and onion powder samples predominantly displaying blue-green colonies. In contrast, salted onions (SO) exhibited compact yellow colonies.

Bacterial identification revealed that, except for the salted onion samples, most of the samples contained Pseudomonas species, which are commonly associated with the softening and spoilage of onions. On the other hand, Staphylococcus species were identified in the salted onion samples. Staphylococcus species are typically found in foods preserved under salty conditions. This finding is particularly noteworthy since Pseudomonas is recognized for its role in spoilage, while Staphylococcus, though pathogenic, appears to thrive in salted environments, consistent with previous studies by Agi et al. (2020).

The Gram staining results indicated that raw, frozen, and onion powder samples were dominated by Gram-negative bacteria, whereas salted onions primarily exhibited Gram-positive bacteria arranged in grape-like clusters. Biochemical tests further confirmed that, with the exception of onion powder, all samples tested positive for catalase activity. This suggests the presence of catalase-positive organisms capable of neutralizing hydrogen peroxide. Specifically, Pseudomonas species were identified in the raw, frozen, and powdered onion samples, while Staphylococcus species were predominant in the salted onion samples, which also demonstrated catalase positivity.

**Table 5: Characteristics and Biochemical Test of Bacterial isolates from Raw and Processed Onion samples during storage**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Characteristics/Tests** | **RO** | **FO** | **OP** | **SO** |
| **Appearance of Colonies on Media plates** | Blue green colonies with characteristic odour | Blue green colonies with characteristic odour | Blue green colonies with characteristic odour | Compact yellow colonies |
| **Cell Morphology** | Short rods | Short rods | Short rods | Cocci arranged in clusters |
| **Gram’s Reaction** | -ve | -ve | -ve | +ve |
| **Catalase test** | +ve | +ve | +ve | +ve |
| **Oxidase test** | +ve |  |  |  |
| **Methyl Red** | -ve | -ve | -ve | +ve |
| **Voges-Proskauer Test** | -ve | -ve | -ve | +ve |
| **Oxidative/****Fermentative** | Oxidative | Oxidative | Oxidative | Fermentative |
| **Indole Test** | -ve | -ve | -ve | +ve |
| **Citrate Utilization** | +ve | +ve | +ve | -ve |
| **Probable Identity** | *Pseudomonas* sp | *Pseudomonas* sp | *Pseudomonas* sp | *Staphyloccus* sp |

*KEYS: RO- Raw onion; FO- frozen onion; OP- Onion powder; SO-Salted onion; -ve: negative; +ve: positive*

**3.3 Preservation Effect on Microbial Growth**

The microbial analysis results align with established knowledge regarding the effectiveness of preservation techniques. Drying, particularly in onion powder, significantly reduces moisture content, creating an unfavorable environment for the growth of bacteria and fungi. Likewise, salting proved highly effective in inhibiting microbial growth by establishing an osmotic environment that is hostile to microbial survival. These findings support the notion that drying, salting, and appropriate freezing are critical methods for extending the shelf life of onions and reducing microbial contamination (Boyer & Huff, 2008; Nnenna, 2020).

Overall, raw onions exhibited the highest levels of microbial contamination, while salted and dried onions demonstrated the lowest. Freezing, although initially effective, was less successful in maintaining low microbial counts due to temperature fluctuations during storage. This highlights the importance of maintaining consistent freezing conditions to prevent the proliferation of microbes.

**3.4 Conclusion**

This study assessed the effectiveness of various preservation methods such as salting, drying, and freezing on onions, with a focus on quality retention and microbiological safety. The results indicated that salting was the most effective method, preserving the highest quality and significantly reducing microbial counts. While freezing initially retained moisture, fluctuations in temperature during storage led to increased mould and yeast growth, emphasizing the need for stable freezing conditions. Drying, by removing moisture, not only improved the protein and fat content of the onions but also enhanced shelf stability and microbiological safety by limiting microbial growth. The moisture, protein, and fat contents varied significantly across the preservation methods, with salting yielding the best overall results. This method not only reduced microbial contamination but also preserved the nutritional quality of the onions. These findings highlight the importance of selecting appropriate preservation techniques for onions to enhance their shelf life while maintaining quality. Salting, in particular, emerged as the most promising method, providing a balance between microbial control and nutrient retention.

**Artificial Intelligence Disclaimer**

**Option 1**

The author(s) affirm that no generative AI tools, including Large Language Models (e.g., ChatGPT Copilot) or text-to-image generation technologies, were utilised in the writing or editing of this manuscript. The writing is duly referenced.

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