



Assessing the Impact of Storage Conditions on the Chemical and Physical Properties of Powdered Infant Formula

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Abstract

This research investigated the influence of room-temperature storage of powdered infant formula on the quality of samples obtained from pharmacies in Khums, Libya. Moisture content, pH, electrical conductivity, total dissolved solids (TSS), and vitamin C concentration were the key quality indicators analyzed. Measurements indicate that product quality decreases significantly during the week following package opening. All samples demonstrated significant increases in moisture content, although one sample's initial moisture content was above expected levels. The subsequent decreases in pH readings and electrical conductivity denoted increasing acidity and complexation with materials such as minerals. TSS readings increased at the same time, which corresponded to moisture uptake. Additionally, despite certain samples being over-fortified in vitamin C to countermeasure an expected nutrient degradation, the concentration of vitamin C decreased consistently across the samples. The findings summarize that storage of powdered infant formula after opening at room-temperature affects powdered infant formula in various aspects affecting physical, chemical, and nutritional safety over overtime.

Keywords: Powdered infant formula, Storage conditions, Physicochemical properties, Nutritional quality

Introduction

A vital food source for babies, powdered infant formula supplies vital nutrients for their development and growth, especially in situations where breast milk is unavailable (Abdel-Gawad et al., 2021). Throughout its shelf life, including storage and transportation, the

product must retain its nutritional and physical quality in order to play this crucial role. Ascorbic acid, also known as vitamin C, is one of the most significant water-soluble vitamins that are added to baby formula. It is necessary for the development of connective tissue and bone, and it boosts immunity (Dutta & Mahanta, 2023). Nevertheless, this vitamin is extremely vulnerable to deterioration during processing and storage due to its high sensitivity to heat, oxidation, and light (Wang & Sun, 2024). According to earlier research, the amount of vitamin C in powdered milk products dramatically drops with time, particularly when exposed to high humidity and temperatures (Gómez-Mascaraque et al., 2022). The storage of powdered infant formula has an impact on physical characteristics in addition to the change in nutritional value. Among those physical characteristics are color, solubility and moisture content (Wong et al., 2023). The moisture content is an important factor in stability because increased moisture content can lead to microbial growth or clumping of the powder. Color changes may indicate undesirable changes in the product, such as the Maillard reaction, which have an impact on the quality of protein and sugars in the product (Al-Khalifa & Al-Jawaheri, 2021). In order to assess the quality of the product as affected by storage conditions, the study seeks to evaluate the changes in vitamin C concentration and important physical characteristics, such as color and moisture content in powdered infant formula. The purpose of this study is to determine the optimal conditions for retaining the nutritional content of the product.

Materials and Methods

Sample Collection

In 2024, five types of baby formula from local pharmacies were collected and stored in a controlled environment in the city of Khums, Libya. Being representative of a diversity of manufacturers, the samples were drawn from different brands of powdered baby formula. The collected samples were maintained and stored in their original, unlabeled packaging prior to testing and assessing their stability and quality during storage.

Materials and Equipment

The study used iodine solution (potassium iodide and potassium iodate), starch solution, and diluted sulphuric acid. All preparations for the study were made using distilled, sterilised water from the steam desalination plant at Khums. The instruments and equipment used in this investigation included an analytical balance, an electric oven, pipettes, burettes, conical flasks, and volumetric flasks of various sizes. There were also physical property measurements conducted using a refractometer, conductivity meter, and pH meter.

Methods of Analysis

The powdered baby formula samples were characterized for physical and chemical properties using standard analytical methods. All measurements were conducted in the laboratory according to established international standards.

Measurement of Moisture Content: The common oven drying procedure was used for the moisture content measurements. The sample was carefully weighed and placed into a clean drying plate at a weight of approximately 5 grams in each sample. The samples were then heated to 102°C for 1 hour in an electric drying oven. Upon drying, the samples were cooled in a desiccator and then reweighed. The moisture content was calculated based on the percentage of the original weight (Wrolstad et al., 2018).

Determination of Vitamin C: Iodometric titration, a recognized method that employs oxidation–reduction reactions, was utilized to ascertain the concentration of vitamin C in the samples (AOAC, 2019). The ascorbic acid (vitamin C) in the samples was titrated with standard iodine solution. This method is known for being quick and accurate for determining vitamin content in foods.

Measurement of Physical Properties: The instruments previously described were used for measuring other physical properties. These included the refractive index measured with a refractometer, pH measured with a pH meter, and electrical conductivity measured with a conductivity meter (Nielsen, 2017).

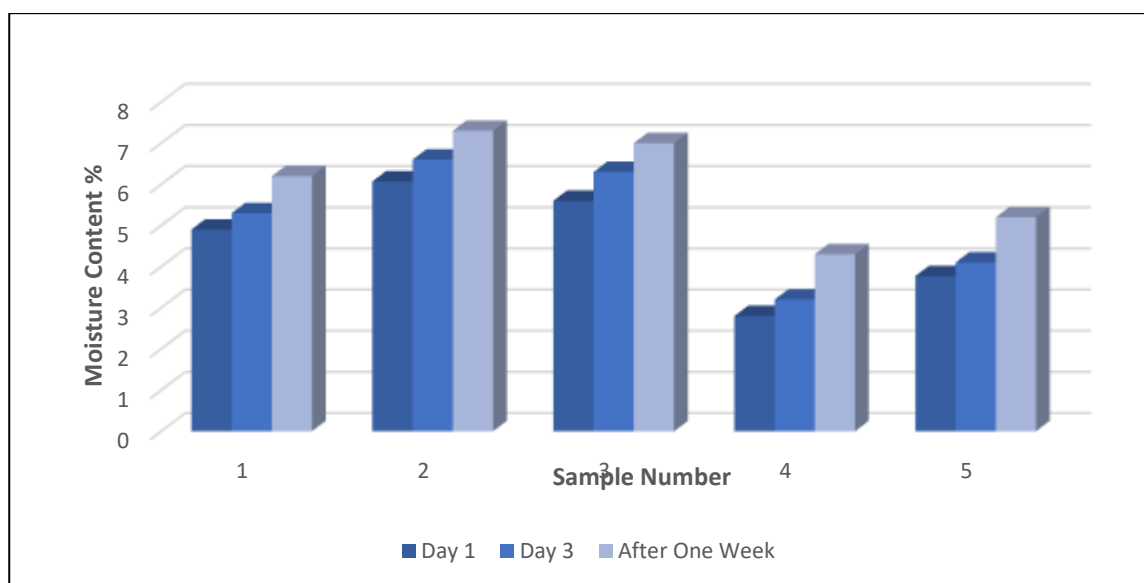
Results and Discussion

Moisture Content

As indicated in Table 1, there was a notable change in the moisture content of the powdered infant formula samples over the one–week storage duration.

Table 1: Changes in Moisture Content (%) of Powdered Infant Formula Samples.

Sample Number	Day 1	Day 3	After One Week
1	4.9	5.3	6.2
2	6.07	6.6	7.3
3	5.6	6.3	7.0
4	2.8	3.2	4.3
5	3.77	4.1	5.2

**Figure 1: Changes in Moisture Content (%) of Powdered Infant Formula Samples.**

The majority of the samples fell within the acceptable international limit for moisture content on Day 1. However, Sample 2 had an uncharacteristically high moisture content of 6.07% and was outside the Libyan standard range of 3–5%. This suggests that Sample 2 may have lost stability prior to the beginning of the experiment due to excess humidity (Wrolstad et al., 2018). The powdered infant formula is hygroscopic and quickly absorbs water from the air after the original package is opened, which aligns with the increased moisture content we observed (Nielsen, 2017). This absorption is a primary factor in product deterioration. High moisture content has been shown to cause particle aggregation, loss of solubility, and increased rates of undesirable chemical reactions such as Maillard browning (Smith et al., 2020) (Al-Khalifa & Al-Jawaheri, 2021). The final moisture content of our samples (4.0 – 7.0%) is in line with that of past research on similar products stored under similar conditions.

The measurement of pH

demonstrates that the pH of powdered infant formula samples changed during storage over a week after opening, as shown in Table 2 and Figure 2. Because any change in pH can signal microbial activity or chemical changes, it serves as a key marker for product quality and safety.

Table 2: Changes in pH of Powdered Infant Formula Samples during Storage

Sample No.	Day 1	Day 3	After One Week
1	7.29	6.80	6.70
2	6.97	6.45	6.35
3	7.08	6.83	6.40
4	6.48	6.40	6.20
5	7.08	6.83	6.55

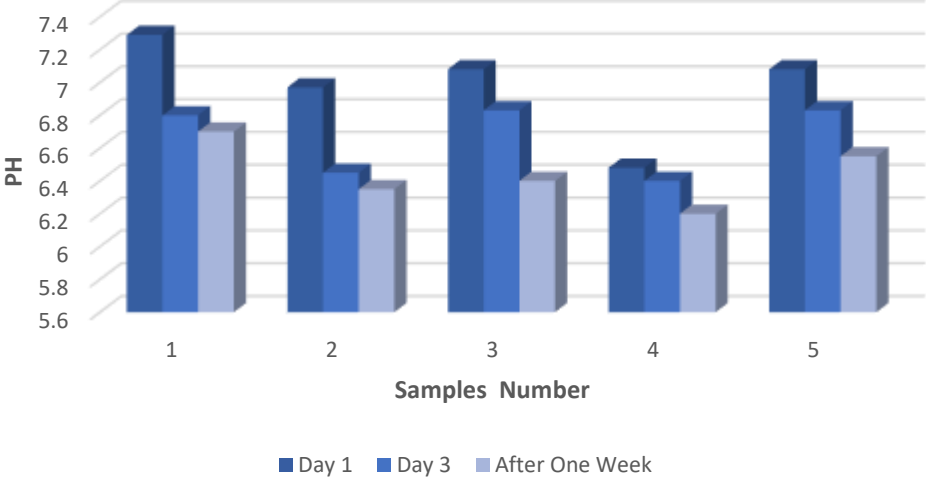


Figure 2: Changes in pH of Powdered Infant Formula Samples during Storage.

According to the typical requirements for high quality powdered infant formula, Day 1 pH values for the samples ranged from 6.48 to 7.29 (Ahmed & Ibrahim, 2021). The highest initial pH value (7.29) was recorded for Sample 1 and the lowest value (6.48) was recorded for Sample 4. During the course of the three-day storage period, all of the samples showed a decrease in pH, and this decrease continued for the duration of the one-week storage time. This decrease is indicative of an increased acidity. One major contributor to this change is the conversion of lactose to lactic acid due to bacterial and enzymatic activity after the formula was exposed to air (Nielsen, 2017). The observed pH decrease may also be caused by other chemical changes, such as Maillard browning. Sample 2 showed the most significant impact on pH from storage conditions. Over the course of one week, Sample 2 pH decreased by 0.62 (from 6.97 to 6.35). These results suggest that certain brands of baby formula may be more susceptible to physical and chemical changes

once opened (Tewari & Singh, 2022). The findings also support earlier work demonstrating that powdered infant formula pH declined when stored in sub-optimal conditions.

Conductivity Measurement

The electrical conductivity of the powdered milk solutions was measured in ms/cm. The results can be seen in Table 3 and below in Figure 3, which illustrate changes that occurred over the week long storage period.

Table 3: Changes in Electrical Conductivity (ms /cm) of Powdered Infant Formula Solutions Over One Week.

Sample No.	Day 1	Day 3	After One Week
1	3.50	3.48	2.16
2	3.48	3.43	2.53
3	2.89	2.47	1.775
4	3.70	3.32	2.32
5	3.55	3.40	2.54

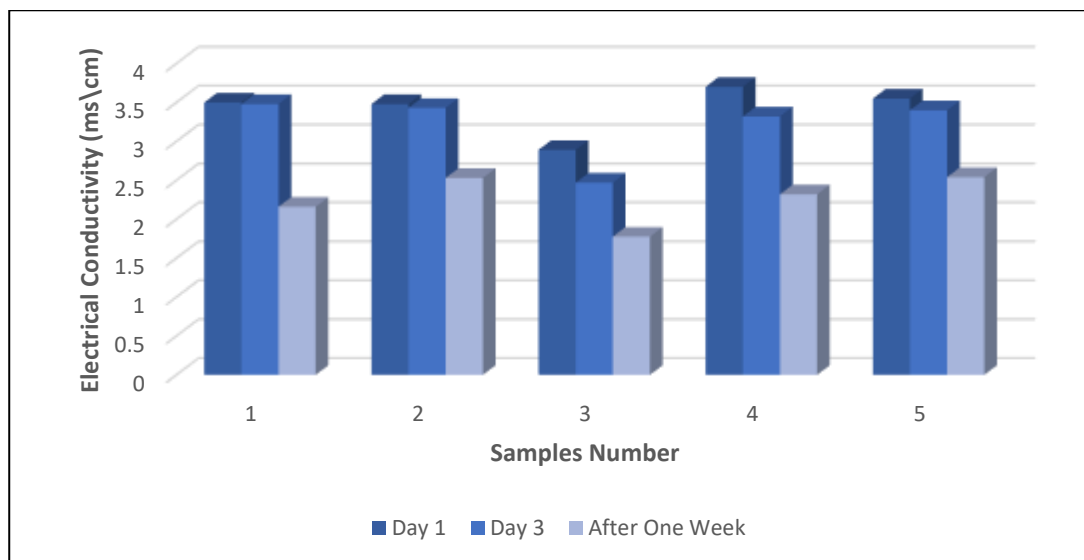


Figure 3: Changes in Electrical Conductivity (mS/cm) of Powdered Infant Formula.

There was some variation in the starting conductivity values for each sample on Day 1; Sample 4 had the highest value at 3.70 mS/cm and Sample 3 had the lowest value at 2.89 mS/cm. The ranges of values for similar milk products fall within that first range (Tewari & Singh, 2022). Over the course of the one-week storage period, the conductivity of all samples decreased significantly rather than increased as expected. The drops in conductivity imply that there are fewer free ions in the solution as time passes. There are several potential explanations for the decreased conductivity. When powdered milk is exposed to air, it can result in various chemical reactions, such as protein denaturation and aggregation. The dissolved minerals and salts in solution, which mainly contribute to the conductivity of the solution, including calcium and magnesium, bind with proteins

during these chemical reactions. By binding with proteins in solution, some of the ions are chelated out of the solution, resulting in a measurable reduction in conductivity (Smith et al., 2020). Additionally, lactose hydrolysis into other compounds may reduce mobility of ions, further lowering the electrical conductivity of the solution.

These data highlight the importance of proper storage, as variations in conductivity are a clear indicator of changes in the underlying physicochemical properties of the product that could compromise the stability and nutritional value of the product.

Total Soluble Solids

The measurements of total soluble solids (TSS) for the powdered infant formula samples are shown in Table 4 below, analyzed on Days 1, 3, and after 1 week of storage.

Table 4: Changes in Total Soluble Solids (TSS) of Powdered Infant Formula Samples.

Sample No.	Day 1	Day 3	After One Week
1	4.7	4.8	5.1
2	4.3	4.5	4.7
3	3.9	4.3	4.7
4	4.1	4.5	4.8
5	4.5	4.8	5.1

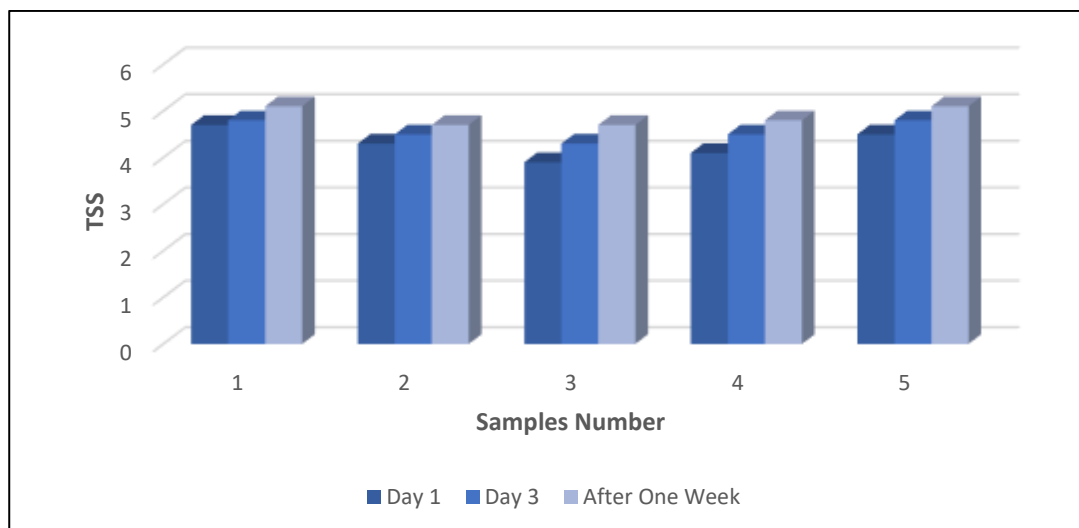


Figure 4: Changes in Total Soluble Solids (TSS) of Powdered Infant Formula Samples.

The findings clearly illustrate a trend: as time in storage increased, so did the total soluble solids for all five samples. On Day 1, the total soluble solids were measured between 3.9 to 4.7. Since these first readings were often below the limits set in Libyan guidelines, it may have been due to some variations at the time of initial make-up or setting when these infant formulas were made. Over the week of storage, the total soluble solids were recorded between 4.7 to 5.1. This increase occurred primarily for the water that was absorbed from the surrounding air upon the opening of the original container. As the

solids absorbed water, some of these solids > were able > to dissolve, thus increasing the total number of soluble solids (or particles) in the mixed solution. (Nielsen, 2017). The results upon conclusion were noted to be slightly less than prior studies. This was likely due to the initial storing. Other variables were discussed that included possible variation in composition due to other manufacturers (i.e., chemical composition) and storing conditions including relative humidity and temperature of each study (Singh & Tewari, 2020).

Vitamin C Content Assessment

Vitamin C (ascorbic acid) content was measured in five powdered infant formula samples on days one and three, and again at one week after storage. Results of vitamin C concentration, in mg/100g, are outlined in Table 5.

Table 5: Changes in Vitamin C Concentration (mg/100g) Over One Week and a Comparison to On-Label Values.

Sample No.	On-Label Value	Day 1	Day 3	After One Week
1	60	66.6	60.7	52.9
2	74	86.5	82.7	69.7
3	90	81.4	78.8	77.8
4	67	60.7	53.7	42.6
5	87	80.1	71.03	65.9

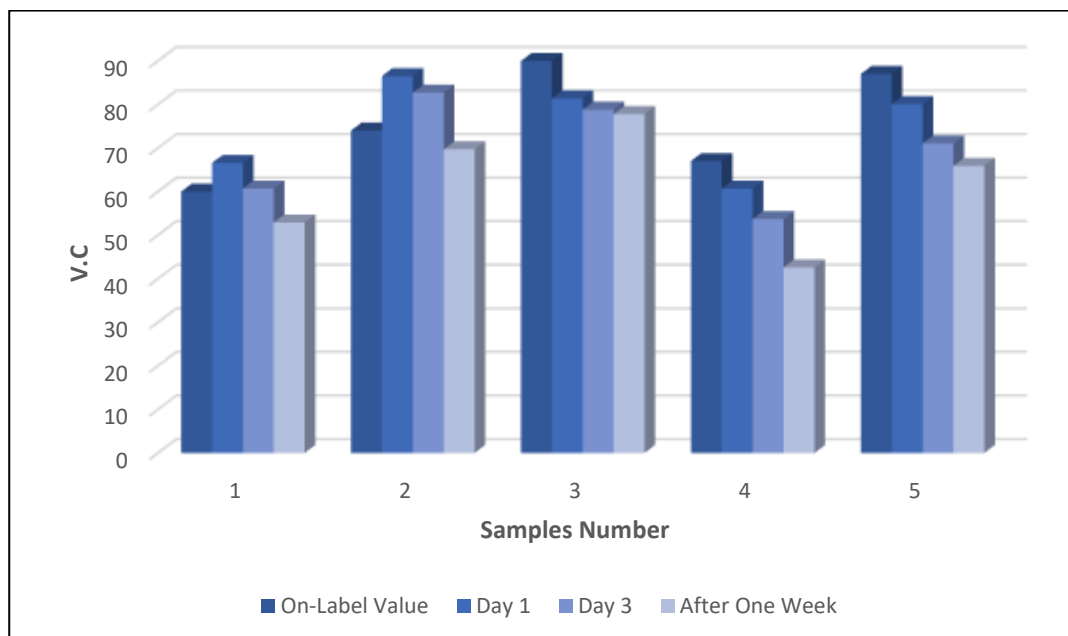


Figure 5: Changes in Vitamin C Concentration (mg/100g) Over One Week and a Comparison to On-Label Values.

Across all samples, the data demonstrated that the vitamin C over time demonstrated a pattern of decrease in all assessed samples. Specifically, Sample 4 revealed the least vitamin C concentration at the start of the experiment (60.7 mg/100g), while Sample 2 had the highest starting concentration (86.5 mg/100g). Vitamin C is among the most unstable vitamins commonly found in foods and it is particularly prone to oxidation, heat, and light and is well known to change and undergo oxidative processes after the first day of testing (Wang & Sun, 2024). An important aspect of this study was to compare the vitamin C concentration measured at Day 1, and values quoted on the label of the product. The results were shown in Table 5 which indicated that the measured and quoted values were consistently similar. Based on our results, we noted that vitamin C concentration in Samples 1 and 2 were greater than the stated concentrations on the product's label, and the other samples were slightly under by about 7–8%. It is common practice for manufacturers to over-fortify their products in order to ensure that the tested nutrient is in the product at the time of the stated shelf life, even at the end of shelf life (Gómez-Mascaraque et al., 2022).

In conclusion, the findings are in accordance with previous studies that suggest optimal storage conditions are needed to preserve the nutritional quality of powdered milk. While vitamin C concentrations may initially be high, the rapid decline of the vitamin also demonstrates the need for consumers to adhere to storage recommendations after opening the product.

Conclusion

This research shows that inappropriate storage following the opening of the container has severely compromised the quality of powdered infant formula. The main cause is moisture uptake which initiates a series of physical and chemical changes. These changes are evidenced by reductions in electrical conductivity and pH, which are indicative of increased mineral binding and increased acidity, respectively. The total soluble solids also increase over time. Most importantly, vitamin C levels deteriorate rapidly. These cumulative changes illustrate that exposure to environmental conditions significantly reduces the nutritional and physical quality of the product.

Recommendations

To maintain the integrity of the infant formula powder after it has been opened, there are a few basic scientific principles that should be followed. Customers should aim to use the product right away and store it in a cool, dry place, such as a cupboard, instead of the refrigerator, where the added humidity will destroy the product faster. The container must be completely and securely sealed after every use. In terms of manufacturing, the quality

of the product could still be maintained post-opening, by utilizing more efficient, airtight packaging materials.

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