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PROCESSING METHODS, STORAGE CONDITIONS, QUALITY, AND SHELF LIFE OF SUNFLOWER (*HELIANTHUS ANNUUS* L.) SEED OIL MARKETED IN DODOMA CITY, TANZANIA

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ABSTRACT

The study assessed the processing methods, quality, storage, and shelf life of sunflower (Helianthus annuus L.) seed oil in Dodoma City, Tanzania, from May 2022 to November 2023. Twenty samples from cold-press extraction "(n=10)" and traditional refining "(n=10)" underwent analysis for various parameters at two time points, 12 and 18 months after manufacturing. Most brands met the Tanzania Bureau of Standards (TBS) limits, but some did not; Odour (1.8±0.20-2.20±0.20, 1.00±0.00-2.20±0.20), taste (2.20±0.20-2.40±0.25, 1.20±0.20-2.40±0.25), colour yellow (38.60±0.40-38.60±0.40, 41.00±0.95-38.60±0.40), colourr red (3.88±0.04-4.18±0.07, 4.00±0.05-4.18±0.07), refractive index (1.44±0.00-1.44±0.01, 1.46±0.00-1.44±0.00), relative density (0.91±0.00-0.88±0.01, 0.88±0.01-9.48±0.08), acid value (0.33±0.01-0.41±0.02, 0.35±0.02-0.41±0.03) mg KOH/g, peroxide value (9.32±0.06-9.48±0.08, 9.08±0.02-9.48±0.08) meq/kg, iodine value (136.6 ±0.98-130.00±2.43,140.20±0.86-130.00±2.43) g/g, and saponification value (174.60± 1.50-174.60± 1.50, 180.40±0.25-180.40±0.25-174.60±1.50) mg/g for crude cold-pressed and refined oils, respectively. There were no significant differences between refined and cold-pressed oils (p > 0.01). Refined oils maintained superior quality over time, with most brands adhering to TBS labelling criteria, all brands had no additives and indicated best-before dates. Quality control measures should be strengthened to ensure all brands meet TBS standards by improving storage practices.

Keywords: Processing, Storage, Quality, Shelf Life, and TBS standards

INTRODUCTION

Oil extracted from sunflower (*Helianthus annuus* L.) seed is one of the world's most widely consumed vegetable oils (Gouzy *et al*., 2016). In many parts of the world, this oil has become a popular alternative to traditional cooking oils due to its high unsaturated fatty acid content (Pal *et al*., 2015), low levels of saturated fats (Anushree *et al*., 2017), and numerous health benefits attributed to its favorable balance of unsaturated and saturated fatty acids (Olesea *et al*., 2013; Adeleke and Babalola, 2020). Furthermore, the oil is valued for its neutral flavor, high smoke point, and versatility (Anushree *et al*., 2017), food processing (Negash *et al*., 2019), and various industrial applications (Majchrzak *et al*., 2018; Adeleke and Babalola, 2020). Tanzania ranks among the top ten global producers of sunflower oilseed (Zeng, 2017), over 50% of sunflower is cultivated in the country (Salisali, 2012; FAOSTAT, 2015; Chappa *et al*., 2022; URT, 2021), distributed as Manyara (22.5%), Kilimanjaro (13.2%), and Singida (8.9%) (URT, 2016; URT, 2021; Msafiri *et al*., 2023).

Sunflower oil extraction is a widespread practice in various regions of Tanzania (URT, 2020). Several processing methods of sunflower seeds on the final product include cold-pressing (Nadeem *et al*., 2015; Taher *et al*.,2017; Devanesan *et al*., 2019), hot-pressing (Taher *et al*.,2017; Norbert and Milena, 2023), and refining processes (Taher *et al*.,2017; García-González *et al*., 2021). Some processing methods involve the addition of synthetic or natural antioxidants, like vitamin E (tocopherols) and phenolic compounds, to protect the oil from oxidative degradation (Achinewhu and Akpapunam, 2005; Taghvaei and Jafari, 2015; Ghendov-Mosanu *et al*., 2023) and enhance the oxidative stability (Muttagi *et al*., 2014; Na *et al*., 2021; Kariminejad *et al*., 2023).

Proper storage conditions are necessary to maintain sunflower oil quality, stability, and nutritional value (Kucuk and Caner, 2005; Ghendov-Mosanu *et al*., 2023); storage in a cool environment at 10°C to 21°C is recommended (Martini and Añón, 2005; Vrbikova *et al*., 2014). Refrigeration extends shelf life (Li and Yu, 2023) while exposure to sunlight and high temperatures accelerates the degradation of oil due to its photosensitivity (Xu *et al*., 2019; de Souza *et al*., 2020), leading to the formation of free radicals (Negash *et al*., 2019) and the development of oxidative rancidity (Tsai *et al*., 2023), resulting in off-flavors (Ahmed *et al*., 1999) and a decrease in nutritional value (Metzner *et al*., 2020). Oxygen causes the oxidation of sunflower oil; therefore, minimizing the headspace in the storage container reduces the amount of air in contact with the oil (Crapiste *et al*., 1999). Using airtight containers and sealing properly preserves oil quality (Ahmed *et al*.,, 1999). Moisture leads to the development of mold and bacteria in the oil (Ramezan, 2004; Abulude *et al*., 2007; Liu *et al*., 2022). Glass or opaque plastic containers with airtight seals are recommended for storing sunflower cooking oil (Tawfik and Huyghebaert, 1999); clear plastic containers are avoided since they provide inadequate protection against light exposure (Holler *et al*., 2023).

The chemical and physical composition of oil vary based on processing methods (Kucuk and Caner, 2005; Zoumpoulakis *et al*., 2017; Adeleke and Babalola, 2020), the source of sunflower seeds (Adeleke and Babalola, 2020), and cultivation practices (Petraru *et al*., 2021). Variations in quality composition impact stability and oxidative resistance (Raffaele *et al*., 2021; Elfalleh *et al*., 2022). The shelf life of sunflower cooking oil varies depending on the oil type, such as refined or unrefined (Ngassapa and Othman, 2012), processing methods, packaging, and storage conditions (Martín-Torres *et al*., 2022), as well as the quality of the sunflower seeds (Adeleke and Babalola, 2020). Fresh, high-quality seeds are less likely to introduce impurities or contaminants that could shorten their shelf life (Muttagi *et al*., 2014).Unrefined sunflower oil, mainly cold-pressed varieties, tends to have a shorter shelf life compared to refined oils (Tsao *et al*., 2021). This is because it retains more natural impurities and antioxidants (Szylowska-Czerniak *et al*., 2022), which contribute to quicker oxidation and spoilage (Kariminejad *et al*., 2023). On the other hand, refined sunflower oil goes through processes to remove impurities, making it more stable (Pal *et al*., 2015) and less susceptible to oxidation (Gharby, 2022). As a result, refined sunflower oil has a longer shelf life. The choice of processing methods, extraction techniques, refining processes, packaging, storage conditions, and the use of antioxidants determine the quality and extend the shelf life of sunflower oil (Nadeem *et al*., 2015; Nde and Anuanwen, 2020). These factors need to be considered and controlled throughout the production and storage processes to produce high-quality oil (Muttagi *et al*., 2014; Pal *et al*., 2015). Depending on the above factors, carefully processed and correctly stored oil has a shelf life of up to two years (Martín-Torres *et al*., 2022).

The growing demand and widespread consumption of sunflower seed oil in the city, along with concerns regarding the variability in processing methods and storage conditions and their potential impact on the quality and shelf life of the oil, necessitated this study. Despite sunflower oil popularity, limited data exists on how these factors influence the final product and comply with local standards. This lack of localized data made it challenging to ensure consistent product quality and safety, thus calling the need for a detailed investigation into these variables. Existing studies have not thoroughly examined the long-term impact of these factors, where variations in processing techniques and storage environments might lead to significant differences in product quality and safety. This study fills a knowledge gap by providing comprehensive data on the quality and shelf life of sunflower seed oil under various conditions. It seeks to understand how different processing methods and storage conditions impact the quality and shelf life of sunflower seed oil. The study lies in its systematic comparison of cold-pressed and traditionally refined sunflower oils over time that informs producers, consumers, and regulatory bodies how these factors influence sensory attributes and chemical properties. The objective of the study was to evaluate the processing methods and storage conditions of sunflower seed oil marketed in Dodoma city, Tanzania.

MATERIALS AND METHODS

Study area

This study was conducted in Dodoma (6° 10′ 43″ South and 35° 45′ 2″ East), the capital city of Tanzania, an administrative and political hub for the country. The choice of this study area was based on several reasons: First, it is situated in an agriculturally rich region where sunflower farming, oil processing, and sale are prominent. Secondly, the city has a diverse population, serving as a distribution point for sunflower cooking oil. Third, it is a semi-arid climate characterised by hot temperatures during the day and cooler evenings, with a distinct rainy season occurring from November to April and a dry season from May to October conditions that may impact the storage and quality of sunflower oil calling for the need to investigate if the shelf life and indicated best before dates align with actual measurements.

Sample collection

The study involved a total of twenty oil samples, cold compressed brands Majira, Kindai, Abay, Kibo, and Gree View (n = 10), and refined brands Sundrop, Ava, Golden Harvest, Sunola, and Bajuun (n = 10) to ensure a representative analysis of both cold-pressed and refined sunflower seed oils available in Dodoma City. This number was chosen to provide a sufficient sample size for comparing different brands and processing methods while considering practical constraints like availability and accessibility.

A purposive sampling technique was employed, where specific brands of sunflower seed oil were selected from various sources, including retail outlets, local markets, small-scale oil mills, and supermarkets. The brands were chosen to represent both cold-pressed and refined categories, with five brands from each category. This approach ensured a diverse range of samples reflecting the market distribution and allowed for a comparative analysis of processing methods and storage conditions.

Sample storage and processing methods assessment

Samples were kept in store at room temperature away from solar radiation and outside the store in open space where they received solar radiation. The original sunflower oil samples before storage were first measured, and the values obtained were recorded. After storage (12 months and 18 months), samples were measured and analysed qualitatively by sensory evaluation and quantitatively in the laboratory, and the results obtained were recorded on the data sheet.

Evaluation of sunflower oil processing methods involved the state of its purity, safety, hygiene, waste management, sustainability and efficiency standards, suitability of materials for storing the oil, packaging hygiene, and the production scale.

Quality measurement and shelf-life assessment

The colour was determined by an automatic colorimeter (Lovibond RT Series Reflectance Tintometer; Lovibond, Amesbury, UK) with three values: L*, a*, and b*. The L* values range from black 0 to white 100, with a* indicating the red (+) to green (-) degree and b* indicating the yellow (+) to blue (-) degree. The method described by AOAC (2005) was employed to determine the refractive index using a refractometer (NYRL-3-Poland). The determination of oil relative density followed the method D1298 described in the American Society for Testing and Materials (ASTM) (Noureddini *et al*., 1992). The standard procedures outlined by Othman and Ngassapa (2012) were followed to determine the acid value, peroxide value, iodine value, and saponification value. Sensory evaluation involved a panel of three individuals who used their senses to evaluate and describe the odour and taste of sunflower oil (Mbela *et al*., 2018). Oil odourr was graded according to the strength of the fragrance using a numerical scale ranging from 1 to 4, where 1 represents no odour, 2 represents mild odour, 3 represents moderate odour, and 4 represents strong odour. To assess the taste of oil samples, panelists rinsed their palates with water between samples to avoid carryover effects; thereafter, they were given small portions of each oil sample to taste using a rating scale defined as 1 for neutral, 2 for mild, 3 for earthy, and 4 for peppery taste. The samples shelf life was assessed under various storage conditions, including room temperature, light exposure, and 12-18 months of storage duration. Sensory attributes and chemical properties were assessed to detect degradation. Regular analyses were conducted at predefined intervals to track the impact of different conditions on the oils quality. The results obtained were compared with established quality and TBS standards for edible oils.

Data analysis

A Statistical Package for the Social Sciences (SPSS Statistics 29) and Excel with statistical analysis Add-ins softwater were used to analyse data in ANOVA to compare data obtained on the quality and shelf life of sunflower cooking oil under different processing methods and storage conditions. Differences in means were assessed, with statistical significance set at $p > 0.01$ unless otherwise stated.

RESULTS AND DISCUSSIONS

Table 1 shows that sunflower oil processing methods in the city ranged from traditional to more modern and efficient techniques. The solvent extraction method utilised a solvent to extract oil from sunflower seeds; small- to medium-scale processors employed the cold pressing method, pressing sunflower seeds to extract oil without using heat to preserve the natural properties of the oil; and traditional methods encompassed conventional techniques of grinding and pressing seeds traditionally. Solvent extraction was of the highest efficiency, yielded large quantities with the highest purity of oil per unit of seeds, and was the most expensive, followed by cold pressing and traditional methods.

All methods were practiced in a safe environment and adhered to hygiene in packaging to lessen the environmental impact. Percent purity varied depending on equipment used, oilseed quality, and local conditions. Solvent extraction and cold pressing methods had waste management practices in place, while traditional methods did not. The choice of method depended on production scale, purity requirements, environmental considerations, available equipment, market demand, and cost constraints. No information was available on customer feedback for any method.

Table1: Sunflower oil processing methods in Dodoma City, Tanzania

Method	Traditional methods	Cold pressing	Solvent extraction refined
Number of facilities	21	12	3
Production (L/ kg of seeds)	0.4	0.5	0.75
Production scale (L/ Hr)	Smal	Moderate	High
Purity (%)	60-70	80-90	90-100
Environmental Impact	No	Yes	Yes
Safety ad hygiene	Yes	Yes	Yes
Waste management	No	Yes	Yes
Consumer feedback	No	No	No
Packaging hygiene	Yes	Yes	Yes

Small-scale producers preferred traditional or expeller pressing methods, while larger commercial facilities utilised solvent extraction and advanced refining techniques to meet market standards. Sunflower oil extraction and refining were followed by packaging in appropriate containers of different sizes. The majority of storage containers used was polyethylenterephthalate (PET) bottles. All manufacturers avoided the use of metal containers in order to maintain the quality of stored oils. No brand was packed in glass bottles, although they are recommended for their lower oxidation values in comparison to PET.

Results present the quality parameters in crude cold-pressed oil (denoted as A-E) and refined oil (denoted as F-J) at different time points: initially (Table 2), 12 months (Tables 3 and 4), and 18 months (Tables 5 and 6) kept inside and outside the store. In tables 2–6, 1 presents no odourr, 2 presents a mild odourr, 3 presents a moderate odour, and 4 represents a strong odour. The taste of sunflower oil was rated from 1 to 4, where 1 is neutral, 2 is mild, 3 is earthy, and 4 is peppery. Initial measurements of both cold-pressed and refined oil are recorded in Table 2. Oil samples were characterized by a mild, nutty aroma and a neutral flavour, which agrees with the findings of Hassan *et al*. (2014), who reported that sensory evaluations of freshly extracted oil had a clear, pale-yellow colour.

Table 2: Quality parameters original values of sunflower oil brands before storage

	Crude cold-pressed oil						**Refined oil**						
Quality parameters	A	B	C	D	E	Mean ± SEM	F	G	H	I	J	Mean ±SEM	TBS Limits
Odour	2	1	2	2	2	1.80±0.20	1	1	1	1	1	1.00±00.00	1
Taste	2	2	3	2	2	2.20±0.20	1	2	1	1	1	1.20±0.20	1
Color (Yellow)	38	38	39	38	40	38.60±0.40	41	44	38	41	41	41.00±9.50	≤ 50
Color (Red)	3.90	3.80	3.80	4.00	3.90	3.90±0.04	4.10	4.00	4.10	3.80	4.00	4.00±0.05	≤ 4.0
Refractive index	1.44	1.43	1.45	1.44	1.44	1.44±0.00	1.46	1.45	1.46	1.46	1.46	1.46±0.00	≤1.48
Relative density	0.91	0.91	0.93	0.91	0.91	0.91±0.00	0.90	0.89	0.89	0.88	0.89	0.89±0.00	≤ 0.92
Acid value	0.31	0.39	0.34	0.37	0.42	0.37±0.02	0.31	0.43	0.38	0.32	0.33	0.35±0.02	≤ 0.60
Peroxide value (meq/kg)	9.46	9.46	9.26	9.16	9.26	9.32±0.06	9.11	9.16	9.06	9.06	9.02	9.08±0.02	≤ 10
Iodine value (g /g)	140	137	134	136	136	136.60 ±0.98	142	141	140	141	137	140.20 ±0.86	110-143
Saponification value (mg/g)	171	178	177	171	176	174.60± 1.50	181	180	180	181	180	180.40±0.25	188-194

Table 3: Quality parameters of sunflower cooking oil brands stored inside the store after 12 months

	Crude cold-pressed oil						Refined oil						
Quality parameters	A	B	C	D	E	Mean±SEM	F	G	H	I	J	Mean ±SEM	TBS Limits
Odour	2	1	2	2	2	1.80±0.20	1	1	1	1	1	1.00±0.00	1
Taste	2	2	3	2	2	2.20±0.20	1	2	1	1	1	1.20±0.20	1
Color (Yellow)	38	38	39	38	40	38.60±0.40	41	44	38	41	41	41.00±0.95	≤ 50
Color (Red)	3.90	3.80	3.80	4.00	3.90	3.88±0.04	4.10	4.00	4.10	3.80	4.00	4.00±0.05	≤ 4.0
Refractive index	1.44	1.43	1.45	1.44	1.44	1.44±0.01	1.46	1.45	1.46	1.46	1.46	1.46±0.01	≤1.48
Relative density	0.91	0.91	0.93	0.91	0.91	0.91±0.01	0.90	0.89	0.89	0.88	0.89	0.89±0.01	≤ 0.92
Acid value	0.32	0.4	0.35	0.36	0.43	0.37±0.02	0.32	0.44	0.37	0.33	0.34	0.36±0.02	≤ 0.60
Peroxide value (meq/kg)	9.47	9.46	9.28	9.17	9.26	9.33±0.06	9.11	9.16	9.08	9.10	9.03	9.10±0.02	≤ 10
Iodine value (g /g)	137	135	131	134	133	134.00±1.00	139	138	137	139	134	137.40±0.93	110-143
Saponification value (mg/g)	171	178	177	171	176	174.60±1.50	181	180	180	181	180	180.40±0.25	188-194

Table 4: Quality parameters of sunflower cooking oil brands stored outside the store after 12 months

	Crude cold-pressed oil						Refined oil						
Quality parameters	A	B	C	D	E	Mean±SEM	F	G	H	I	J	Mean ±SEM	TBS Limits
Odour	2	2	3	2	2	2.20±0.20	1	2	1	1	1	1.20±0.20	1
Taste	2	2	3	3	2	2.40±0.24	1	2	1	1	1	1.20±0.20	1
Color (Yellow)	38	38	39	38	40	38.60±0.40	41	44	38	41	41	41.00±0.95	≤ 50
Color (Red)	4.10	4.00	4.00	4.10	4.20	4.08±0.04	4.10	4.00	4.10	3.80	4.00	4.00±0.05	≤ 4.0
Refractive index	1.44	1.43	1.45	1.44	1.44	1.44 ±0.01	1.46	1.45	1.46	1.46	1.46	1.46±0.00	≤1.48
Relative density	0.90	0.91	0.92	0.91	0.9	0.91 ±0.01	0.89	0.9	0.87	0.9	0.88	0.89±0.01	≤ 0.92
Acid value	0.32	0.41	0.36	0.39	0.44	0.38±0.02	0.33	0.48	0.37	0.33	0.39	0.38±0.02	≤ 0.60
Peroxide value (meq/kg)	9.56	9.51	9.30	9.26	9.29	9.38±0.06	9.20	9.27	9.10	9.09	9.12	9.16±0.03	≤ 10
Iodine value (g /g)	135	131	130	132	135	132.60±1.03	136	135	135	137	134	135.40±0.51	110-143
Saponification value (mg/g)	171	178	177	171	176	174.60±1.50	181	180	180	181	180	180.40±0.25	188-194

Table 5: Quality parameters of sunflower cooking oil brands stored inside the store after 18 months

Quality parameters	Crude cold-pressed oil A	B	C	D	E	Mean±SEM	Refined oil F	G	H	I	J	Mean ±SEM	TBS Limits
Odour	2	2	3	2	2	2.20±0.20	1	2	1	1	1	1.20±0.20	1
Taste	2	2	3	3	2	2.40±0.25	1	2	1	1	1	1.20±0.20	1
Color (Yellow)	38	38	39	38	40	38.60±0.40	41	44	38	41	41	41.00±0.95	≤ 50
Color (Red)	4.10	4.00	4.00	4.10	4.20	4.08±0.04	4.10	4.00	4.10	3.80	4.00	4.00±0.05	≤ 4.0
Refractive index	1.44	1.43	1.45	1.44	1.44	1.44±0.00	1.46	1.45	1.46	1.46	1.46	1.46±0.00	≤1.48
Relative density	0.89	0.90	0.90	0.91	0.90	0.90±0.00	0.88	0.90	0.87	0.90	0.86	0.88±0.01	≤ 0.92
Acid value	0.34	0.31	0.34	0.30	0.35	0.33±0.01	0.32	0.32	0.37	0.38	0.39	0.36±0.02	≤ 0.60
Peroxide value (meq/kg)	9.48	9.47	9.28	9.19	9.28	9.34±0.06	9.13	9.18	9.10	9.08	9.02	9.10±0.03	≤ 10
Iodine value (g /g)	135	133	127	131	130	131.20±1.36	136	130	134	136	131	133.40±1.25	110-143
Saponification value (mg/g)	171	178	177	171	176	174.60±1.50	181	180	180	181	180	180.40±0.25	188-194

Table 6: Quality parameters of sunflower cooking oil brands stored outside the store after 18 months

Quality parameters	Crude cold-pressed oil A	B	C	D	E	Mean±SEM	Refined oil F	G	H	I	J	Mean ±SEM	TBS Limits	P value
Odour	2	2	3	2	2	2.20±0.20	1	2	1	1	1	2.20±0.20	1	*p = 0.02*
Taste	2	2	3	3	2	2.40±0.25	1	2	1	1	1	2.40±0.25	1	*p = 0.03*
Color (Yellow)	38	38	39	38	40	38.60±0.40	41	44	38	41	41	38.60±0.40	≤ 50	*p = 0.02*
Color (Red)	4.30	4.00	4.10	4.10	4.40	4.18±0.07	4.00	3.70	4.20	3.90	4.00	4.18±0.07	≤ 4.00	*p = 0.02*
Refractive index	1.44	1.43	1.45	1.44	1.44	1.44±0.00	1.46	1.45	1.46	1.46	1.46	1.44±0.00	≤1.48	*p = 0.13*
Relative density	0.86	0.89	0.86	0.90	0.90	0.88±0.01	0.87	0.89	0.86	0.89	0.85	9.48±0.08	≤ 0.92	*p = 0.11*
Acid value	0.34	0.44	0.37	0.41	0.48	0.41±0.02	0.37	0.51	0.38	0.36	0.41	0.41±0.03	≤ 0.60	*p = 0.20*
Peroxide value (meq/kg)	9.66	9.66	9.36	9.26	9.46	9.48±0.08	9.31	9.27	9.20	9.19	9.23	9.48±0.08	≤ 10	*p = 0.03*
Iodine value (g /g)	130	125	125	138	132	130.00±2.43	130	131	130	132	129	130.00±2.43	110-143	*p = 0.21*
Saponification value(mg/g)	171	178	177	171	176	174.60±1.50	181	180	180	181	180	174.60±1.50	188-194	*p = 0.11*

Table 7: Quality of sunflower oil brands initially, 12 months, and 18 months after storage kept inside and outside the store

	Crude cold-pressed oil					Refined oil						
Quality parameters	Original	12 Inside	12 Outside	18 Inside	18 Outside	Original	12 Inside	12 Outsude	18 Inside	18 Outside	TBS Limits	P value
Odour	1.80±0.20	1.80±0.20	2.20±0.20	2.20±0.20	2.20±0.20	1.00±00.00	1.00±0.00	1.20±0.20	1.20±0.20	2.20±0.20	1	*p = 0.11*
Taste	2.20±0.20	2.20±0.20	2.40±0.24	2.40±0.25	2.40±0.25	1.20±0.20	1.20±0.20	1.20±0.20	1.20±0.20	2.40±0.25	1	*p = 0.02*
Color (Yellow)	38.60±0.40	38.60±0.40	38.60±0.40	38.60±0.40	38.60±0.40	41.00±9.50	41±0.95	41.00±0.95	41.00±0.95	38.60±0.40	≤ 50	*p = 0.03*
Color (Red)	3.90±0.04	3.88±0.04	4.08±0.04	4.08±0.04	4.18±0.07	4.00±0.05	4.00±0.05	4.00±0.05	4.00±0.05	4.18±0.07	≤ 4.0	*p = 0.20*
Refractive index	1.44±0.00	1.44±0.01	1.44 ±0.01	1.44±0.00	1.44±0.00	1.46±0.00	1.46±0.01	1.46±0.00	1.46±0.00	1.44±0.00	≤1.48	*p = 0.21*
Relative density	0.91±0.00	0.91±0.01	0.91 ±0.01	0.90±0.00	0.88±0.01	0.89±0.00	0.89±0.01	0.89±0.01	0.88±0.01	9.48±0.08	≤ 0.92	*p = 0.31*
Acid value	0.37±0.02	0.37±0.02	0.38±0.02	0.33±0.01	0.41±0.02	0.35±0.02	0.36±0.02	0.38±0.02	0.36±0.02	0.41±0.03	≤ 0.60	*p = 0.02*
Peroxide value (meq/ kg)	9.32±0.06	9.33±0.06	9.38±0.06	9.34±0.06	9.48±0.08	9.08±0.02	9.10±0.02	9.16±0.03	9.10±0.03	9.48±0.08	≤ 10	*p = 0.20*
Iodine value (g /g)	136.6 ±0.98	134±1.00	132.60±1.03	131.20±1.36	130.00±2.43	140.20 ±0.86	137.40±0.93	135.40±0.51	133.40±1.25	130.00±2.43	110-143	*p = 0.11*
Saponification value (mg/g)	174.6± 1.50	174.60±1.50	174.60±1.50	174.60±1.50	174.60±1.50	180.40±0.25	180.40±0.25	180.40±0.25	180.40±0.25	174.60±1.50	188-194	*p = 0.21*

The statistical comparison in Table 6 reveals no significant differences between crude cold-pressed and refined sunflower oils across most quality parameters. P-values indicate that differences in odourtaste, colour, refractive index, relative density, acid value, peroxide value, iodine value, and saponification value are not statistically significant (p>0.01).

Results of sunflower oil brands stored inside and outside the store after 12 and 18 months met the specified quality limits for most parameters except odour (1.80±0.20-2.20±0.20, 1.00±0.00-2.20±0.20), taste (2.20±0.20-2.40±0.25, 1.20±0.20-2.40±0.25), and relative density (0.91±0.00-0.88±0.01, 0.89±0.00-9.48±0.08) for crude cold pressed and refined oil, respectively, which exceeded the TBS limit, suggesting that the quality of oil was inconsistent when subjected to different storage conditions for a given period, which depended on the duration of storage, light, and temperature. There is minimal variation of 38.60±0.40 to 41.00±0.95 in the yellow colour, indicating stability over the storage period. The red colour parameter also stays within the specified limits (3.88±0.04–4.18±0.07) for both types of oil and under different storage conditions. There were slight variations in the red colour, but they remained within the acceptable range. Physical attributes of colour and odour varied in different brands, indicating differences in processing methods, storage conditions, oil source, and handling (Metzner *et al*., 2020; Lu *et al*., 2022; Rhazi *et al*., 2022). Over time, especially in light-exposed storage conditions, the oil colour darkened and became less appealing. Oils stored inside the store at room temperature retained their original colour for a longer period of time. Prolonged storage, particularly in conditions exposed to higher temperatures, led to the development of off-flavours and rancidity, suggesting poor quality, undesirable flavours, bitterness, and deteriorated oil (Negash *et al*., 2019).

The relative density of oils decreased from 0.91±0.00 to 0.88±0.01 for crude cold compressed oil and from 0.89±0.00 to 0.88±0.01 for refined oil with an increase in temperature and storage duration; this may be due to exposure of oil to sunlight outside in the open air, where its molecules gained energy and moved more, causing a decrease in density, suggesting the observed changes in the oil composition (Noureddini, 1992; Achinewhu and Akpapunam, 2005; Yuda *et al*., 2014). Acid value, refractive index, and peroxide values were fairly constant throughout storage. The rate of increase for acid values (0.37±0.02-0.41±0.02, 0.35±0.02-0.41±0.03) was pronounced in crude cold-pressed and refined oil samples, respectively, stored for 18 months. High acid values could be due to possible contamination and inadequate processing (Noureddini, 1992), suggesting an elevated level of free fatty acids. Peroxide values increased (9.32 ± 0.06–9.48 ± 0.08, 9.08 ± 0.02–9.48 ± 0.08) for crude cold-pressed and refined oil samples with extended storage, with variations depending on storage conditions. Samples of refined oil stored under light-exposed conditions displayed the highest peroxide values of 9.48 ± 0.08, while those stored inside the store at a lower temperature exhibited more stability. Elevated temperatures accelerate oxidation reactions, leading to an increase in peroxides (Tauferova *et al*., 2021). On the other hand, higher peroxide values signify that the oil has undergone oxidation. A high peroxide value is considered an indicator of poor quality or improper storage conditions, probably associated with factors such as exposure to light, air, or high temperatures. Oils with high peroxide values are more likely to have a shorter shelf life and may not be suitable for consumption.

The iodine values were generally within the acceptable range and decreased during the storage period, indicating adequate unsaturation levels. The iodine value decreased from 136.6 ± 0.98 to 130.00 ± 2.43 for crude compressed oil and from 140.20 ± 0.86 to 130.00 ± 2.43 for refined oil. A decrease in the iodine value of vegetable oil could imply a reduction in the level of unsaturation (Olesea *et al*., 2013; Mbela *et al*., 2018), which has implications for the nutritional quality and stability of the oil. Oils with lower iodine values tend to be more stable but may also have a higher proportion of saturated fats, which could impact their health profile (Othman and Ngassapa, 2012; Adeleke and Babalola, 2020). According to Ngassapa and Othman (2012), continuous or prolonged exposure to light and the presence of oxygen accelerate the degradation of oils and reduce the iodine value through oxidation reactions. Saponification values stand still at 174.6 ± 1.50 for crude cold-pressed oil and 180.40 ± 0.25 for refined oil. These results suggest that optimal storage conditions, temperature control, light protection, suitable packaging, and limited oxygen exposure significantly extend the shelf life of sunflower oil. Adeleke and Babalola (2020) and Martín-Torres *et al.* (2022) reported that the shelf life of sunflower oil can be prolonged or shortened based on how it is handled, the processing method employed, and storage conditions. High-quality, freshly extracted oil is likely to have a longer shelf life compared to oil with impurities or poor processing (Tsao *et al*., 2021; Szylowska-Czerniak *et al*., 2022). Exposure to direct sunlight degraded sunflower oil, causing a reduction in its shelf life (Negash *et al*., 2019; Xu *et al*., 2019).

These results provide information about the quality of the sunflower oil before and after storage, and any deviations from the specified limits indicate areas for improvement in the production and storage processes.

It was observed that unrefined sunflower oil, particularly cold-pressed varieties, exhibited a relatively shorter shelf life in comparison to refined oils, in agreement with Tsao *et al*. (2021). This discrepancy is explained by Szylowska-Czerniak *et al*. (2022), who found higher retention of natural impurities and antioxidants in unrefined oil, which, in turn, contributes to a faster occurrence of oxidation and spoilage, as observed by Kariminejad *et al*. (2023). Conversely, according to Pal *et al*. (2015) and Gharby (2022), refined sunflower oil undergoes processes aimed at eliminating impurities, resulting in enhanced stability and reduced susceptibility to oxidation. Consequently, refined sunflower oil demonstrated an extended shelf life, as indicated in Table 7. The statistical comparison in Table 7 shows that both crude cold-pressed and refined sunflower oils exhibit slight changes in quality parameters over time, with storage conditions affecting odour, taste, colour, and other properties. However, most parameters remain within acceptable limits, indicating minimal significant differences ($p>0.01$) between storage durations and conditions. Depending on the aforementioned factors, meticulously processed and appropriately stored oil maintains quality for up to two years.

Table 8: Packaging material and labelling of sunflower oil in Dodoma City, Tanzania

	Cold pressed oil brands				Refined oil brands						
Container type & labelling	A	B	C	D	E	F	G	H	I	J	Compliance
Name of the product	1	1	1	1	1	1	1	1	1	1	C
Grade	2	2	2	2	1	1	1	1	2	1	NC
Trade name or brand	1	1	1	1	1	1	1	1	1	1	C
Producer name & address	2	1	1	1	1	1	1	1	1	1	NC
Batch or lot number	2	2	1	1	2	1	1	1	2	1	NC
Date of packing	1	2	2	1	1	1	1	1	2	1	NC
Net weight	1	1	1	1	2	1	1	1	1	1	C
Country of origin	2	2	2	2	2	2	2	2	2	2	NC
Year of harvest	2	2	2	2	2	2	2	2	2	2	NC
TBS standard mark	2	1	1	1	2	1	1	1	1	1	NC
Storage condition	1	2	2	1	1	1	1	1	1	2	NC
Expiry date	2	1	1	2	1	1	1	1	1	1	NC
Opaque container	2	2	2	2	2	2	2	2	2	2	NC
Additives	2	2	2	2	2	2	]2	2	2	2	C

Numerical values 1-Present, 2-Missing, C-Complied, NC-Not Complied.

All brands indicated a best-before date of one year, which is a good period to maintain the best oil quality within the time limit set by Martín-Torres *et al*. (2022). On the other hand, the climatic area of the study area did not affect the quality of oil available in retail outlets, local markets, small-scale oil mills, and supermarkets within an 18-month period. Table 8 provides results for the packaging material and labelling of sunflower oil brands for both cold-pressed and refined sunflower oil brands in accordance with TZS 538 (TBS, 2012). The compliance column indicates whether the brands comply with certain criteria, with "C" denoting compliance and "NC" denoting non-compliance.

Results suggest that, while both cold-pressed and refined sunflower oil brands generally comply with labelling criteria, there are notable non-compliances, especially in the cold-pressed sunflower oil brands, regarding grade, producer name and address, batch or lot number, date of packing, country of origin, year of harvest, TBS standard mark, storage conditions, and expiration date. These non-compliances raise concerns about the accuracy and completeness of the information provided on the packaging and may impact consumer safety, trust, and safety. Discrepancies in labelling call for regular checking that requires adherence to packaging and labelling standards to ensure consumer safety and product quality.

CONCLUSIONS

The majority of crude cold-pressed and refined oil brands met the TBS limits for all quality parameters after being stored inside at room temperature and outside the store for 12 and 18 months respectively, suggesting that most oils maintained their quality at acceptable levels during the storage period, with a few exceptions. Proper refining and optimal storage enhance oil stability, preventing rancidity and nutrient degradation, thereby ensuring a longer shelf life and maintaining product quality for consumers. The study recommends improving quality control measures, processing standards, and storage facilities in the local sunflower oil industry to ensure high-quality products. It also advises implementing awareness campaigns, training programs, proper labelling, and educational initiatives for producers and retailers to enhance oil safety and increase consumer satisfaction. Further research should explore consumer preferences, microbial quality, contaminant presence, and sustainable processing practices for sunflower oil, ensuring microbial safety and reducing environmental impact.

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Declaration of Conflict of Interest

I affirm that there are no personal relationships with individuals or organisations that could potentially influence the interpretation or presentation of the research.

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