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Gap in Supply and Demand: Impact on Milk Safety

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Abstract
Milk is a commonly consumed complete food by people of various age groups. Milk adulteration is a rising public health concern. India, a developing nation, faces a huge gap between the demand and supply due to shortage in milk production. The present review article attempts to understand the standards laid down by Food Safety and Security Authority of India (FSSAI) for milk quality. To achieve this quality and the need to bridge the demand and supply gap of milk lays a huge impact to the daily lives of individuals. This is the major reason for the rise in adulteration of milk. In order to meet the quality standards and shelf life, chemicals are added to adulterated milk and prolonged consumption of adulterated milk has long lasting health ill-effects which can even be fatal. Therefore, detection of adulterants in milk becomes mandatory and of utmost importance from both the standpoint of an individual's heath and from food safety perspective for larger public good.

Key words*: demand-supply gap, adulterants, adulteration, detection methods, FSSAI, health hazards, milk, milk quality*

Introduction

1. Milk - a complete food and source of nutrition for humans

Being rich in nutrients, milk is one of the important items in daily diet which is consumed by people of all age groups [1]. Milk is defined as 'the normal mammary secretion derived from complete milking of healthy milch animal without either addition there to or extraction there from' [2]. On an average, the consumption of milk and milk products is slowly increasing worldwide. Consumption of milk in India is dated back to 1000BC as described in the scriptures. In the earlier days, milk and dairy products were consumed in huge amounts and were popular only among the royalties. In 1970, owing to the 'Operation flood', White revolution began in India which made milk and dairy products available to all at affordable prices.

It has often also been observed that particularly in India, consumption of milk increases mainly during festivals and fasting periods like Navratra or Ramadan. A study conducted among Ghanian boys indicated an increase in dietary diversity scores during Ramadan as their diet mainly consisted of Vitamin A rich fruits and milk, whereas the inclusion of roots and tubers in diet was reduced. Weight loss was also observed for a month which was later regained post the fasting period [3].

Being an important part of diet, globally, it is important that the safety and quality of milk need to be ensured [4]. The safety and quality of milk supplied can only be confirmed by thorough testing for presence of adulterants. As the demand for milk slowly rises, adulteration becomes an easy way to bridge the supply gap and for quick monetary gain [5]. We undertook a study for understanding the consumption scenario of milk on the global scale, gap between demand and supply of milk, commonly added adulterants, and their resulting effects on human health.

2. Demand of milk and resulting increase in adulteration

With reference to the statistical data presented by National Dairy Development Board, India, the annual production of milk for the year 2018 – 19 was 187.7 million tonnes and the per capita availability of the

same was 394gms/day. Milk constitutes an important part of individual diet as it consists of all kinds of nutrients and micronutrients making it a complete food [6]. It consists of vitamins, minerals, proteins, fats etc. Most importantly it's a good source of Vitamin D that helps in proper absorption of calcium. Right from infancy up to old age, milk is consumed either with breakfast, or consumed at night. Some individuals or students even consume milk to fulfil a minor hunger pang during a hectic day. Milk products too, such as clarified butter, butter, buttermilk, curd, yoghurt, and cheese are some of the most popularly consumed items worldwide. These milk products can be easily digested by people who are lactose intolerant [7].

As per the definition issued by FSSAI, adulteration of food is defined as 'the addition or subtraction of any substance to or from food so that the natural composition and quality of food substance is affected' [8]. According to the 2019 global survey, highest consumption of cow milk was recorded in India, approximately 78 million tonnes [9]. Milk, being white in color and a complex emulsion, can easily be adulterated. Chemicals used as adulterants have adverse effects on human health if consumed for prolonged periods. They are added to milk in order to match the quality standards. The adulterants of milk can be categorized along with their function broadly as shown Figure 1:

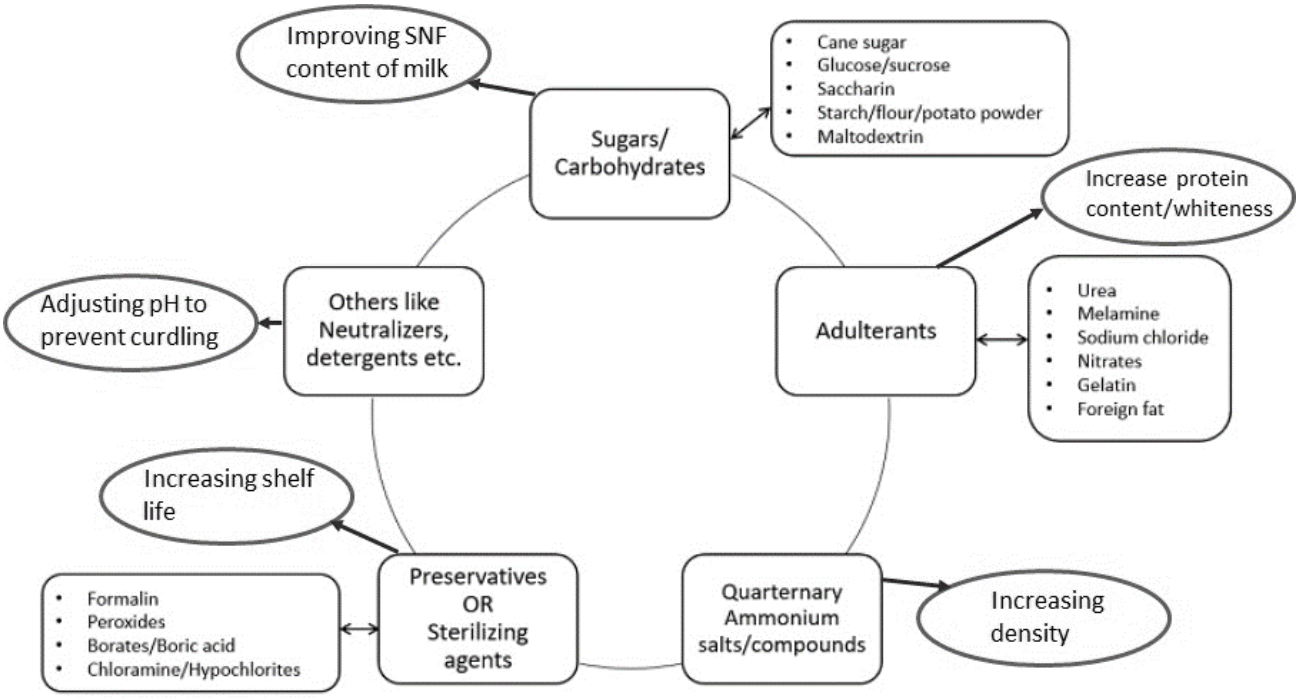

Fig. 1: Adulterants and their functions

India being a country primarily comprising of rural areas, only 18-20% of the milk comes from proper organized sectors [10]. Rest of it is from small rural dairies which become an easy target for adulteration by middlemen for economic gains [11]. The division between organized and unorganized sectors can be better explained with the help of the following image, Figure 2:

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Fig. 2: Organized and unorganized dairy sectors in India

During emergency situations that call for global restrictions, the food availability is worst hit. People are not able to procure necessary food items. However, on the positive side the government makes tremendous efforts to make essential items available in all the cities for e.g.: vegetables, fruits, milk, other food items and medicines. In times of crises, the demand for milk sores high because it is considered to be a nutrient rich food item. However, due to movement restrictions supply chains are disrupted and the dairy industry faces loses [12]. Despite shortage of food and supplies, farmers are forced to dump their fresh produce as they're unable to get them to the markets. As per a statement by National Dairy Development Board (NDDB) in India, milk sales cooperatives suffer as much as a 15% reduction. Despite the initial hit, dairy sector seems to be in a good shape as farmers convert their surplus into milk products and door to door delivery of milk and dairy products. With the recognition of milk being a complete source of nutrition which can also boost immunity there is growing emphasis on adding milk and dairy products in daily diet [13] [14].

3. Long term effects of adulterants and synthetic milk

Today, despite repetitive testing of milk to ensure quality and safety, a lot of adulterants go undetected. In view of the fact that milk is an important part of daily diet of people belonging to various age groups, consumption of adulterated milk poses a serious public health challenge. In extreme cases it has been found that adulterated milk can cause heart problems, cancer, weight gain, hormonal imbalances in growing children, and in some cases it can even prove to be fatal [15] [16]. In one of the recent adulteration detection attempts, 61% of milk samples in Ahmedabad, Gujarat, India were found to be adulterated with chemicals such as maltodextrin and aflatoxins that can cause weight gain and are carcinogenic respectively [17]. In 2018, 19,000L of adulterated milk was destroyed in Mumbai as it was laced with excessive maltodextrin, sugar, and ammonium sulphate. These can cause severe damage to kidneys and heart. In certain cases adulterated milk has also been attributed as the cause of gynaecomastia [18]. Another 2019 study indicated that 7% milk samples were found to be unfit for human consumption as they were laced with contaminants such as aflatoxin, antibiotics, pesticides and adulterants such as urea, hydrogen peroxide, etc. In the same study 41% of milk samples in Delhi were found to be non-compliant with the FSSAI standards of SNF or fat [19]. As per the standards set by FSSAI, most of the milk samples fail to comply with the standard quality parameters due to low SNF levels. The minimum fat and SNF content in each type of milk differs, but for the most common cow's milk, minimum milk fat content must reach 3.2% and SNF content must be 8.3% [20] [21] [15] [16]. Some of the most commonly found adulterants in milk in India are summarized in the Figure 3:

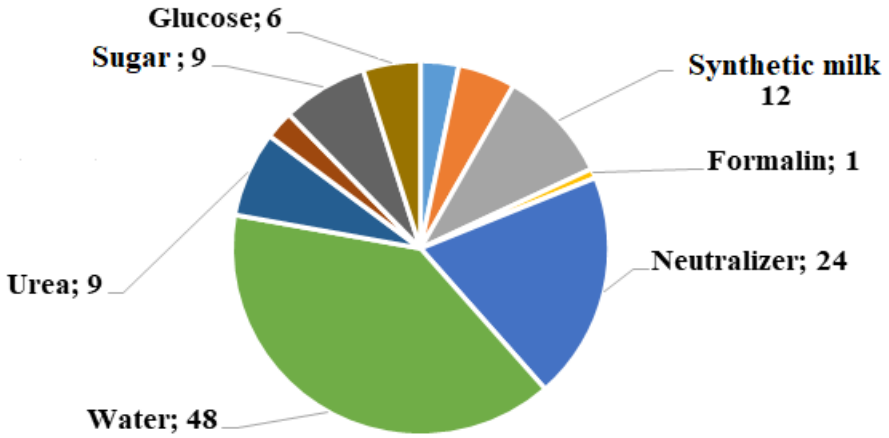

Fig. 3: Common adulterants found in milk and their percentages

The latest survey of milk samples conducted by the NDDB, however revealed the presence of adulterants like urea, hydrogen peroxide, and detergents only in a few samples among the 6000+ which were tested [22]. Although the samples tested positive for the presence of sulphates, FSSAI recently has removed ammonium sulphates as contaminants in milk due to their natural presence [23]. Some of the major adulterants added to milk to maintain its quality and shelf life as per the standards, have been highlighted in the sections below:

3.1 Detergents

Detergents are a category of milk adulterants which exhibit harmful effects on human health. Addition of detergents contributes to changes in milk properties such as decrease in moisture, microbial load and yellowness [24]-[26]. During milk adulteration, detergents help with the emulsification of oil in water thereby giving a frothy solution [15]. Ingestion of these detergents, masked as drinking adulterated milk, can cause gastrointestinal complications [27] [28]. Chemicals found in detergents for eg: - dioxane, sodium lauryl sulphate, formaldehyde, etc. have been found to be carcinogenic and also are responsible for causing organ toxicity. As they are the main ingredients for cleansers, the ingestion can prove to be fatal or cause nausea, and diarrhoea [29].

3.2 Formalin

Formalin, 37% aqueous solution of formaldehyde, is added to milk as a preservative as it inhibits milk curdling and bacterial growth thereby increasing its shelf life. Addition of formalin is hazardous for human health. However, according to WHO report on formalin, maximum level of formalin tested (i.e., 0.15%) was up to 10-fold greater (i.e., 0.22 mg/kg) than levels in milk from control cows fed whey without added formalin. Concentrations in the fresh milk (i.e., from Holstein cows, morning milking) ranged from 0.013 to 0.057 mg/kg, with a mean concentration (n = 18) of 0.027 mg/kg, while concentrations in processed milk (i.e., 2% milk fat, partly skimmed, pasteurized) ranged from 0.075 - 0.255 mg/kg, with a mean concentration (n = 12) of 0.164 mg/kg. Somewhat higher concentrations in the commercial 2% milk were attributed to processing technique, packaging, and storage, but these factors were not assessed further. Several studies on testing for formalin in milk and for understanding the health effects of formalin are summarised in the Table 1.

Table 1: Effects of consumption of formalin present in adulterated milk

Effects	Type of study	Citation	Year
Fever, shallow respiration, weak irregular pulse, blindness and unconsciousness	Formalin found by chemical detection of milk samples from Multan	[30]	2014

Decreases the fat and protein content in milk by binding to various molecular sites, and affects its digestibility	Analysis of effects of formalin on various milk components	[31]	2014
Consumption of formalin on a regular basis can be injurious to the nervous system, kidney and liver, and may cause asthma, pulmonary damage and cancer	It was found that UHT and powdered milk samples contained greater quantity of formalin owing to milk preservation and processing techniques.	[32]	2018
	Detection of formalin in milk samples using advanced optical fibre-based sensors with a sensitivity range between 0.2mg/L-0.6mg/L	[33]	2020

3.3 Melamine

Melamine is an organic white solid compound which is a trimer of cyanamide. It mainly contains 67% nitrogen by mass and hence addition to milk increases its nitrogen content thereby increasing its apparent 'detectable' protein content. Addition of melamine in milk was identified as the main cause of food related safety issue as it led to major health issues in infants and children who consumed milk laced with it. Cyanuric acid (CA), another thiazine contaminant found during the investigation, has similar effects as melamine [34]. Since then, melamine addition to milk has been a cause of major concern in countries facing the problem of milk adulteration. Some of the health effects of melamine are summarized in Table 2:

Table 2: Effects of melamine on human health due to consumption of adulterated milk

Effects on health	Study type	Citation	Year
1. Low dosage exposure leading to urolithiasis and deterioration of kidney functions 2. Stone formation and other adverse effect on renal tubules 3. Induction of renal damage by increasing oxidative stress and its activation of transforming growth factor-β in human renal proximal tubular HK-2 cells	Epidemiological studies for urinary biomarkers induced due to chronic low dosage exposure of melamine in tableware factory workers	[35]	2020
Cytotoxic and genotoxic effects of co-exposure to melamine and CA in human kidney 293 cells	MTT assay of the kidney cells based on varying concentration ratios of melamine: CA (100:1, 10:1, 1:10, 1:100). No deleterious effects observed at 0.5mg/mL, however a dose response was observed with decreased cell viability at higher concentration. Higher levels of CA revealed greater cytotoxicity and DNA damage, as seen by comet assay	[34]	2020
Infants might be exposed to melamine antenatally due to consumption of contaminated food by mother	Cohort study of mother's milk and infant characteristics like birth weight, height Melamine has also been reported in mother's milk: Milk samples collected on 5^{th} and 15^{th} day, postpartum, and in between 4^{th} and 10^{th} week. 16.7% mothers had melamine positive samples. Melamine was detected in 32.2% and 24.4% of the 1^{st} and the 2^{nd} milk samples. Z scores for weight and height were found to be lower in infants fed on melamine positive mother's milk	[36]	2020

Nephrotoxicity hazard due to consumption of melamine	Measurement of urine melamine concentration in 908 individuals in Shanghai. Estimation of daily intake and corresponding hazard quotient determination on the basis of age and sex. 24-hour intake recall study to identify possible risky foods. Melamine detected in approximately 85% urine samples (2.524ug/g)	[37]	2019
Development of kidney damage and urolithiasis in children due to consumption of melamine contaminated milk powder	Cohort study conducted in children aged 6 years with a history of consuming melamine contaminated milk powder showed presence of urinary microprotein in urine samples collected at 6 and 18 months. Out of 8335 children screened, 102 were diagnosed with urolithiasis. Post 6 and 18 months, the rates increased to 91.4% (96/105) and 89.2% (91/102) respectively. 90.3% patients had spontaneously passed a stone 18 months later.	[38]	2016

3.4 Urea

Another nitrogen rich adulterant added to milk, apart from melamine, as a preservative is urea. Urea is generally added in the preparation of synthetic milk to raise the SNF value and increase non-protein nitrogen content. It also adds viscosity to milk thereby giving a feeling of thick milk. However, urea is found to have a lot of effects on human health and hence is important to be detected in milk. The following table summarizes the details of effects of urea along with techniques developed for its detection:

Table 3: Effects of urea on human health due to consumption of adulterated milk

Effect on health	Detection technique/type of study	Citation	Year
Kidney and renal failures, ulcers, liver damage, cancer, indigestion, acidity. Might also lead to vomiting, gastritis, and nausea	Use of Surface enhanced Raman scattering (SERS) of silver coated gold particles that formed a coffee ring like pattern on application of 2ul of adulterated milk on a surface coated with the synthesized nanoparticles.	[39]	2019
Liver (degenerative and necrotic changes in hepatocytes and lymphoid follicle formation) and Kidney (fatty changes in the perirenal tissue, mild necrosis, glomerulitis, and leukocytic infiltration)	48 mice were fed urea adulterated milk for 28 days and tissues were analysed on 7^{th} and 28^{th} day of the study. The severity of effects of urea on the tissues was observed to have increased during the feeding period from little on 7^{th} day upto maximum on 28^{th} day.	[40]	2001
Kidney and liver damages, leading to infant death in certain cases.	Detection of urea derivatives in skim milk and non-fat milk powders	[41]	2016
Greater than 70mg/dL consumption of urea from milk can have deleterious effects on human health as it can cause indigestion, renal failure, urinary tract obstruction, gastrointestinal bleeding and cancer	Isolation of urea specific DNA aptamer having selective affinity. The method does not involve use of enzymes. Gold nanoparticles are used to transduce the aptamer signals that are bound by urea thereby changing their color. As the aptamer is highly selective for urea, other milk adulterants do not cause interference in detection.	[42]	2015

3.5 Synthetic milk

Adulteration has taken a new turn towards production of synthetic milk which is comparatively more hazardous than consuming adulterated milk as it is made completely from chemicals only [43]. As defined by Dr. Waite, artificial milk can be categorized as 'imitation' and 'synthetic' milk varieties, wherein imitation milk is the chemically formulated milk whereas synthetic milk is more nutritive and refers to milk formulations used for infants [43]. However, over the years, as adulteration increased, milk became synthetically manufactured by replacing milk fat with vegetable fat and adding adulterants in order to maintain shelf life and physical parameters [44]. The properties of synthetically produced milk are made to mimic natural dairy milk by addition of water, cane sugar or glucose, urea, detergents, and starch [29] [45] [46]. Addition of water from an unreliable source might cause bacterial contamination, urea added to increase the nitrogen content is reported to be carcinogenic, ingestion of detergents can lead to neurotoxicity, nephrotoxicity, renal damage, etc. and addition of neutralizers to maintain acidity of milk can cause heart burns and abdominal pains [30]. It becomes mandatory to check milk quality as the maximum cases of adulteration using synthetic milk are reported from the unorganized milk sector [10].

4. US FDA vs FSSAI regulations for testing adulterants in milk

As stated earlier, milk adulteration is a constantly growing problem on a global level as it directly causes harm to human health. In order to effectively test milk samples for adulterants US FDA follows the AOAC protocols and in India FSSAI has laid down standard protocol manuals for testing adulterants in milk and milk products[47]-[48]. However, all these protocols have been found to be procedures that need a large quantity of milk for analysis. Also, not all major adulterants are tested prior to sales because if that is done, then considering the shelf life of milk, it might perish before being consumed. Currently, milk samples are being tested based on the major criteria of electrical conductivity and pH [15], [49]–[51].

There are a lot of methods being used for detection for adulterants in milk samples. Some of them such as HPLC, GC, LC-MS need complex sample pre-treatments whereas other paper card based methods like MilkPad and µPad use the milk sample directly [33], [54], [56], [55]. However, these paper card-based methods can only be used to detect a few adulterants in samples. Based on the survey being conducted by FSSAI, it's important that milk be tested for specific adulterants, namely cellulose, maltodextrin, boric acid, SNF, glucose, detergents, nitrates, hydrogen peroxide, fat, sugar, vegetable (foreign) fat, urea, neutralizers, and starch. In future if an inexpensive rapid assay is developed to detect these adulterants as identified by FSSAI, it would not only help bridge the gap in research but also provide a quick way of quality analysis.

5. Conclusion

This review hereby briefs about the cause for adulteration of milk and the reason why detection of adulterants becomes extremely important. Being a nutrient rich complex emulsion, milk is considered as a complete food. Regular consumption of milk has its own advantages and a few disadvantages as well. However, prolonged consumption of adulterated milk has been observed to be hazardous to human health. Adulteration of milk is a growing concern in developing countries, including India. Rising population along with the ever-increasing demand vs supply gap becomes the main reason of adulteration to meet the regulatory standards laid down for milk. Hence, it becomes mandatory to test milk for adulterants before it enters the supply chain.

Declarations

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Consent for publication: Not applicable.

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