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Processing of mulberry leaves: A review

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Abstract

Mulberries are recognized botanically as *Morus* which is a species of blossoming plants in *Moraceae* family. The mulberry leaves are used as a functional food, mostly in the form of herbal tea. The drawback in the traditional method of mulberry leaf processing is the loss of antioxidant properties during drying. Hence, this manuscript focuses on different techniques used in the processing of mulberry leaves. Drying is the most important unit operation for the processing of mulberry leaves and antioxidant properties are directly dependent on drying temperature (40-70 °C). The extraction yield, solvent consumption, extraction time and quality of extracts can be improved by the use of high-pressure, microwave, ultrasound, and supercritical fluids. The encapsulation process provides the stability and improves the shelf-life of bioactive components in mulberry leaves. The leaves extract in different value added form significantly helps to lower blood sugar, inflammation levels, and fighting against heart disease.

Keywords: Antioxidant, drying, encapsulation, extraction, herbal tea

Abbreviations

GAE: Gallic acid equivalents

DW: dry weight

DNJ: 1-deoxynojirimycin

PLE: Pressurized liquid extraction

PhA: Phenolic Acids and Fla: Flavonols contents.

AA: Ascorbic Acid

Db: Dry basis

DM: Dry mass

1. Introduction

The mulberry (*Morus alba*) is basically a deciduous, wild-growing plant grown up in temperate, tropical and subtropical regions. The leaf of the plant is widely used in sericulture as a sole food source for silkworm, *Bombyx Mori* L. Apart from the latex of tree which is a milky white sap and mildly toxic to humans, the leaves contain vitamin C (160-280 mg/100g), zinc (0.22-1.12 mg/100 g), calcium (380-786 mg/100 g), iron (4.70-10.36 mg/100 g), tannic acid (0.04 to 0.08 %) and neutral detergent fibre (8.15 to 11.32 %) (Srivastava *et al.*, 2006) [1]. Mulberry leaves have numerous bioactive compounds that mitigate human health problems (Chan *et al.*, 2016) [2]. Mulberry leaves have been used as natural and traditional medicine. Several value-added products are developed from mulberry leaves such as mulberry tea, smoothie, salads, supplement capsules, dry powder, oil, dehydrated mulberry leaf powder-based tomato soup and nutritional masala biscuits as shown in Fig 1. Among them, mulberry tea is the most popular. The bioactive components present in mulberry leaf such as 1-deoxynojirimycin (DNJ), gamma-aminobutyric acid (GABA), phytosterol, quercetin, flavonoids help to control blood sugar level, maintains blood pressure, reduce cholesterol, prevent liver cancer, prevent oxidation, respectively. The vitamins such as vitamin A, B₁, B₂, C proffer healthy eyes, body immunity, body tissue repairing and healthy skin. The extract and the products of the mulberry leaves are very helpful to combat diseases like diabetic, cardiovascular diseases, cancer, inflammation and Alzheimer. The native red mulberry (*Morus Rubra*), the east Asian white mulberry (*Morus Alba*) and the south-western Asian black mulberry (*Morus Nigra*) are the three prime types of mulberry trees (Yigit *et al.*, 2010) [3]. In India, the major mulberry cultivation areas are in the tropical (Karnataka, Andhra Pradesh and Tamil Nadu) and sub-tropical (West Bengal, Himachal Pradesh and the north-eastern) zone and some parts of the temperate region.

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Perhaps, *Morus indica* is the most cultivated species of *Morus*. The most cultivated varieties are Kanva-2, S-54, S-36, V-1, DD, S-34, S-13, MR-2, S-1, Goshorami, G-4 *etc.* These varieties are generally across the south Indian states, eastern, north east region as well as Jammu & Kashmir both under irrigated and rain-fed condition (Datta, 2000) [4]. In China, major cultivated varieties of mulberry are Tong Xiang Qing, Hong Cang Sang, Hu Sang 197, Hu Sang 199, Nong Sang 8, Yu 2, Xiao Guan Sang, Da Hua Sang, Hei You Sang, *etc.* Mostly cultivated across the north, north west, yellow river and Yangtze river regions (Huo, 2000) [5].

1.1. Value-added products of mulberry leaves

Apart from an enormous use in sericulture as feed for silkworms, the foliage of mulberry is used as a dairy animal feed for its optimistic influence in milk production (Gupta *et al.*, 2005) [6]. Ramya and Chandrashekhar, (2020) [7] prepared nutritional masala biscuits using a combination of mulberry leaves dry powder with wheat flour, green masala, sugar, baking powder, salt and butter. The dehydrated mulberry leaf powder-based tomato soup is another example of mulberry leaves value-added product (Singh and Tripathi, 2016) [8]. In Thailand, the processing of mulberry tea prepared by brewing the fresh leaves, vaporizing, aerating, roasting, kneading,

drying with hot air and finally grinding to powder form (ACFS, 2009) [9]. Killedar and Pawar, (2017) [10] standardized the procedure for preparation of herbal tea from mulberry plant leaves. For the preparation of the flavoured herbal tea, the mulberry leaves were blended with a different combination of tulsi and ashwagandha for better health benefits and taste without any caffeine. The organoleptic properties of the prepared herbal tea were creamish green in colour, virulent in taste and pH in between 8 to 9. For consumption of mulberry tea, 200 to 250 ml water and one teaspoon of mulberry leaves powder were taken. The water was heated at 71 to 93 °C with a combination of mulberry, tulsi and ashwagandha (5:0, 4:1, 3:2 ratios), respectively. Additional beneficial ingredients that can enrich the health-boosting power of tea were the core consequence of this research. The mulberry leaves for tea can be processed by fermentation also (Zeng *et al.*, 2013) [11]. The optimized fermentation temperature for the preparation of mulberry tea was 30 °C for 5 hours. The 1-deoxynojirimycin (1-DNJ), total flavonoids (F), total polysaccharides (S), polyphenols (P), free amino acids (AA), rutin and quercetin (Q) of the fermented mulberry black tea was increased by 3.06 %, 17.13 %, 33.07 %, 86.46 %, 37.5 % and 6.86 %, respectively compared with fresh mulberry leaves.

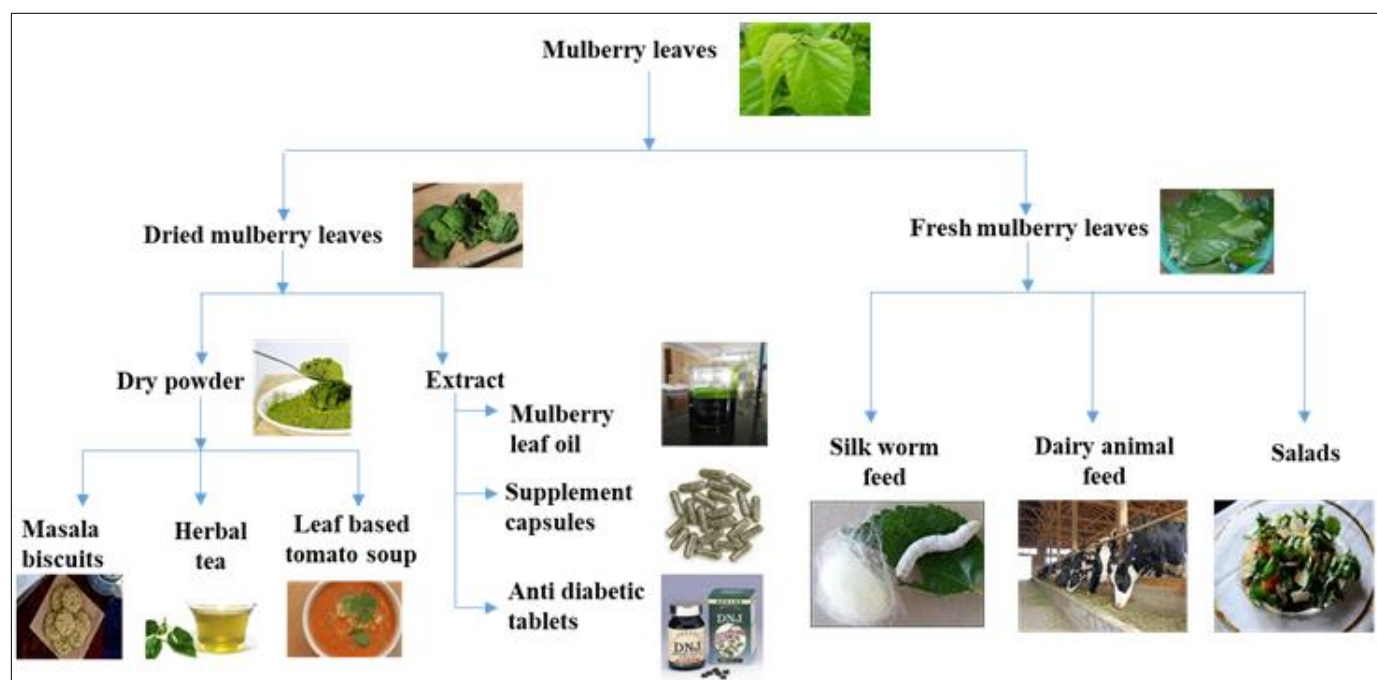


Fig 1: Pictorial flow chart of mulberry leaves value added products

2. Post-harvest processing of mulberry leaves

2.1. Drying of mulberry leaves

Drying is a simultaneous heat and mass transfer process which involves removal of water from a solid. Killedar and Pawar, (2017) [10] reported that for the preparation of herbal tea, the drying operation is most important. Nevertheless, the bio-active components that are present in mulberry leaves are highly heat-sensitive, selection of appropriate temperature and

time of drying is a perplexing job. Traditionally, some of the rural places in India, the sun drying, shade and hot air drying are very popular for drying of any biological materials. However, sun drying and hot air drying are a time-consuming process and also degrades the quality of the final product. The drying methods, retention of nutritional content after drying and overall study outcomes have been summarized in Table 1.

Table 1: Different drying methods and their aspects of nutritional contents in Mulberry leaves (*Morus alba*)

Sl. No.	Drying methods	Temperature (°C)	Nutritional contents after drying	Study outcomes	Authors
1	Convective oven drying	60 for 60 min.	Phenolic Acids (mg/g): gallic acid (0.019), protocatechuic acid (0.166), 4-hydroxybenzoic acid (0.112), chlorogenic acid (5.388), ferulic acid (0.379). Flavonols (mg/g): rutin (2.413),	The degradation (24 %) and enhancement (22%) of phenolic acid and flavonol were exposed when drying at 90 and 30 °C. Drying at 60 °C had the	Przeor <i>et al.</i> , (2019) [12]

			isoquercitrin (1.323), astragalalin (1.081).	highest efficiency of phenolic acids and flavonols contents.	
2	Freeze drying	-50 (20 pa) for 6 hrs.	Free radical scavenging activity was 44.2 ± 0.006 % at concentration of 0.99 mg/mL. Highest ferric reducing antioxidant power (maximum absorbance of 0.26 ± 0.0012). The total sugar content of polysaccharides (MLP) was 69.40-83.70 %, high uronic acid content, β -configuration of sugar present in freeze-dried leaves.	The highest yield (6.789 %) of polysaccharides extracted. The extraction yield was 28.88 % higher than hot-air drying. The lipid peroxidation (MDA) activity was 95.45 %.	Ma <i>et al.</i> , (2018) ^[13]
3	Tunnel drying	40 for 60 min.	The average anti-oxidant activity was the value of IC ₅₀ (half maximal inhibitory concentration) of 89.43 ± 37.65 ppm.	The average value of colour and aroma at 40 °C were 3.45 ± 0.51 and 3.37 ± 0.42 , respectively.	Taufik <i>et al.</i> , (2016) ^[14]
4	Hot air convective drying with Ultrasound pre-treatment.	60 for 101.5 min.	Total chlorophyll was 2.62 ± 0.09 mg/g of dried sample (ds), total phenolics was 65.83 ± 0.88 mg gallic acid/g of ds, total flavonoid was 64.32 ± 1.69 mg rutin/g of ds, antioxidant ability was 765.44 ± 16.9 μ mol of Trolox/g of ds, 1-deoxyynojirimycin (DNJ) was 3.19 ± 0.18 mg/g of ds, gamma-aminobutyric acid (GABA) was 0.70 ± 0.02 mg/g of ds.	The drying time was reduced from 101.5 min (control sample) to 74.0 min. Total processing time was reduced by 17.2%. The total energy consumption was 0.68 kW-hr. Total energy consumption was saved by 17.3% compared with the control sample.	Tao <i>et al.</i> , (2016) ^[15]
5	Oven drying	50 for 4 hrs.	Total phenolic content was 687.5 ± 52.8 mg gallic acid equivalents (GAE)/100 g, ascorbic acid content was 68.1 ± 1.1 mg/100 g, ascorbic acid equivalent antioxidant capacity was 430.7 ± 31.4 mg AA/100 g, ferric reducing power was 3.1 ± 0.2 mg GAE/g, effective chelating concentration was 5.6 ± 0.6 mg/mL, chlorogenic acid was 151.2 ± 15.9 mg/100 g of fresh leaves, rutin was 50.8 ± 0.3 mg/100 g of fresh leaves.	The methanol concentration of 70% (v/v) was found to be effective for extraction of nutritional contents after drying. Water activity (a _w) after oven drying (50 °C) of the cut leaves (0.358 ± 0.019) was low compared to the uncut half leaves (0.475 ± 0.034). The extraction efficiency of phenolic content for the cut leaves was 77.5 % after oven drying (50 °C).	Tan <i>et al.</i> , (2015) ^[16]
6	Far infrared radiation with hot air (FIR-HA) drying	40 for 50 min.	The percentage inhibition of 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical was 76.39 ± 0.17 , ferric reducing antioxidant power (FRAP) was 227.64 ± 0.68 μ M Feso ₄ /g dry sample, phenolic compounds (mg/g) were gallic acid (4.36 ± 0.01), protocatechuic acid (2.70 ± 0.02), benzoic acid (34.53 ± 0.05), chlorogenic acid (12.98 ± 0.01), vanillic acid (0.83 ± 0.02), caffeic acid (2.05 ± 0.02), syringic acid (3.72 ± 0.14), ferulic acid (197.80 ± 3.39), sinapic acid (6.87 ± 0.09).	The moisture content (db) was reduced to 7 % within 50 min. The colour of the leaves after far infrared radiation hot air (FIR-HA) drying was L* (15.17 ± 0.74), a* (-5.00 ± 0.40) and b* (9.46 ± 0.24), respectively.	Wanyo <i>et al.</i> , (2011) ^[17]
7	Hot air drying	60 for 7 hrs.	Chlorogenic acid was 988 mg/100 g of dry weight, quercetin 3-(6-malonyl)glucoside) was 538 mg/100 g of dry weight, rutin was 331 mg/100 g of dry weight, isoquercitrin was 90 mg/100 g of dry weight, astragalalin was 43 mg/100 g of dry weight.	Addition of 0.1 % (v/v) formic acid to the extract was able to prevent the loss of polyphenolic compounds, mulberry leaves dried by air-drying at 60°C after being frozen showed significantly lower levels of polyphenolic compounds.	Katsube <i>et al.</i> , (2009) ^[18]
8	Heat pump dehumidified drying	40 for 110 min.	Rutin content was 375.29 ± 0.15 mg/g dry weight, moisture content was 81.15 % (db), protein was 19.5 % (db), fibre was 21.68 % (db), ash content was 0.14 % (db), fat was 10.34 % (db), carbohydrate was 48.69 % (db).	Drying time was 110 min, higher rutin and Hue angle (121.04°) was observed compared to tray drying. Effective moisture diffusivity was 2.705×10^{-10} m/s. Modified Page model was found more effective to describe the mass transport behaviour. Low energy consumption and economic benefits.	Phoungchandang <i>et al.</i> , (2008) ^[19]

A number of drying methods and pre-drying treatments, investigated in mulberry leaves varieties. The drying methods and temperatures significantly affect the bioactive compounds present in mulberry leaves. However, far infrared radiation, freeze and heat pump dehumidified drying offer high quality dried leaves in terms of bioactive compounds in mulberry leaves. But in comparison of low capital investment for industrial application the heat pump dehumidified drying is more economical over far infrared radiation and freeze drying.

2.2. Extraction of the bio-active components of mulberry leaves

Solid-liquid extraction is the heart of the process for the

processing of the mulberry leaves. Since plant material contains only small amounts of bio-active compounds, therefore the selection of a suitable extraction method is most important. However, pre-treatments such as suitable drying and grinding methods to form powder are essential before the extraction process. Several parameters such as extraction time, temperature, pH etc. significantly affect the quality of the extract. However, currently a few alternative processes such as high-pressure extraction, microwave, supercritical extraction *etc.* have been commercially used. These methods are quicker and offer a high yield, which has an edge on other methods. The optimized extraction conditions and yield obtained from various extraction methods have been summarized in Table 2.

Table 2: Extraction of bioactive compounds from mulberry leaves

Sl. No.	Extraction methods	Extraction conditions	Effect on nutritional contents	Study outcomes	Authors
1	Aqueous extraction	60 min in counterflow with water at 90 ± 5 °C and pH 6.0 ± 0.5 (1:10 m/v) using a twin-screw continuous extractor.	Extracted 1-deoxynojirimycin (DNJ) content was 1.21 ± 0.02 mg/g dry mass (DM), DNJ content (3.45 mg/g DM) in the powder extract was four times higher than in dry mulberry leaves (1.03 mg/g DM).	Extraction yield of 10–15 kg/hr.	Przygonski <i>et al.</i> , (2019) ^[20]
2	Solvent Extraction	The solvent concentration of 39.30 % at 70.85 °C for 120.18 min, liquid/solid ratio of 34.60:1.	Scavenging of 2,2-azinobis-(3-ethylbenz-thiazoline-6-sulphonate) radical and 1,1-diphenyl-2-picrylhydrazyl radical. Compacted the growth of <i>Bacillus pumilus</i> , <i>Staphylococcus aureus</i> , <i>Bacillus subtilis</i> .	The yield of extracted flavonoids was 50.52 mg/g.	Cui <i>et al.</i> , (2019) ^[21]
3	Ultrasound-assisted water extraction (UAWE)	The temperature at 55 °C for 15 min and solvent: solid ratio of 85 ml/g.	The chlorogenic acid was 3.47 ± 0.06 mg/g dry weight (dw), kaempferol was 1.39 ± 0.02 mg/g dw, quercetin hydrate was 1.92 ± 0.01 mg/g dw and 16 more phenolic compounds were the major outcomes.	Higher extraction yields were obtained at a lower temperature.	Cavuldak <i>et al.</i> , (2019) ^[22]
4	Ultra-sound Extraction	Ultrasonic power of 100 W, the heating power of 600 W, the frequency range of 40-100 Hz, the temperature of 57 °C for 80 min with liquid per solid ratio of 53 ml/g.	Addition of quercetin (10 µg/ml) for the improvement of anti-oxidant properties, extracted polysaccharides were recommended as an antioxidant enhancer.	Extraction yield of polysaccharides was 6.92 ± 0.29 % and an inversely propositional relationship was perceived between anti-oxidant property and high concentrated mulberry leaf extracted polysaccharides.	Zhang <i>et al.</i> , (2015) ^[23]
5	Super-critical fluid extraction (SFE)	The pressure of 200 bar, the temperature of 50 °C and dynamic extraction time of 80 min.	DNJ enriched extract was obtained with high extraction efficiency (96.46 %).	The extraction yield was 3.41 %.	Ramya <i>et al.</i> , (2016) ^[24]
6	Solvent Extraction	60 % ethanol extract.	High amount of total phenolic content (122.2 ± 5.3 mg gallic acid equivalents/g dry leaf) plus antioxidant properties (DPPH radical scavenging activity was 10.5 ± 0.2 mmol trolox/g dried leaf). Flavonoids (mg/g dried leaf) such as rutin (0.5±1), quercetin (1.1), isoquercetin (0.8 ± 0.1) were existing.	For microcapsules, 60 % ethanol (pH 4) also provided the high yield (50.3 ± 0.3 %) and efficiency (13.6 ± 0.9). The encapsulation yield (69.5 ± 0.6 %) was highest for coating material concentration of 7.5 % (w/v).	Peaparkdee <i>et al.</i> , (2016) ^[25]
7	Microwave Extraction	Microwave power of 602.28 W for 11.41 min.	1-deoxynojirimycin (DNJ) extracted from mulberry tea was effective to control blood sugar level or prevention of diet-induced obesity.	Extraction yield of 1-deoxynojirimycin (DNJ) was 0.19 %. The optimized model equation's coincidence rate was 99.58 %.	Liu <i>et al.</i> , (2014) ^[26]
8	Ultra-high pressure extraction (UHPE)	Alcohol concentration of 73 % for 3 min with pressure at 400 MPa.	The DNJ was released from the cells of mulberry leaves very easily with increasing pressure and time.	The maximum yield of DNJ was 0.0931 %, less extraction time and high extraction yield.	Zhang <i>et al.</i> , (2014) ^[27]
9	Pressurized liquid extraction (PLE)	The temperature at 50 °C for 5 min with 0.05 g of sample.	The DNJ was 2.44 ± 0.50 mg/g dry leaves (dl), fagomine was 0.48 ± 0.15 mg/g dl, myo-inositol was 8.90 ± 1.88 mg/g dl, glycosyl-inositols was 0.35 ± 0.06 mg/g dl (one-cycle of PLE extraction).	The extraction yield was same as conventional (90 min and solvent required 30 ml for 1g of the sample) but time requirement in PLE system was very less (5 min). Lower solvent consumption (1.39 ml for 0.05 g of sample), and higher selectivity.	Sanchez <i>et al.</i> , (2013) ^[28]
10	Microwave-assisted extraction method (MAE)	The microwave power level of 560 W for 5 min, the ethanol concentration of 60 % and material/solvent ratio of 1:15.	Flavonoids from mulberry leaves had shown significant anti-fatigue effects.	The extraction yield was rapidly increased in the first 5 min of extraction so it was unnecessary to carry experiments more than 5 min.	Li <i>et al.</i> , (2009) ^[29]
11	Macro-porous resin extraction	Resin type H103, pH of 8, the temperature at 90 °C for 4 hrs, the solid-liquid ratio of 1:40.	The recovery and purity of total flavonoids in the final product were 90.57 and 76.33 %.	Separation of total flavonoids from natural products.	Wang <i>et al.</i> , (2008) ^[30]

Over the past few years, the novel extraction techniques continuously developed with the aims of reducing processing time, solvent consumption and simultaneously increasing extraction efficiency. For this reason, the application of ultrasound, super critical fluid, microwave, ultra-high pressure has been adopted to enhance the quality of mulberry leaves extract. The ultrasound assisted extraction technology is effective for extraction of valuable molecules e.g.

polysaccharides, phenolic compounds (Table 2). However, it has some demerits regarding unstable compounds extraction due to the wave amplitudes fluctuation. The microwave assisted extraction method also shows an edge over conventional extraction in terms of yield but it's not suitable for extraction of heat sensitive compounds due to high temperature and less versatility for industrial application. Except the extraction time which is comparatively low, the

extraction yield of pressurize liquid extraction method is same as conventional extraction methods. Moreover, in terms of yield, solvent consumption, extraction time the super critical fluid extraction has been an efficient method for extraction of bioactive components from mulberry leaves.

2.3. Bio encapsulation of the bio-active components of mulberry leaves

The micro-encapsulation process has found wide applications in pharmaceutical and food industries. Spray drying is popular for micro-encapsulation because of its ability to provide stability of active components at lower storage costs. The carrier materials are used to obtain good product recovery and maltodextrins serve as a great carrier material. Maltodextrin is applied in the products that are difficult to dry such as fruit juices, flavourings to reduce stickiness and for improving the product stability (Pujari and Jadhav, 2019) [31]. Pujari and Jadhav, (2019) [31] conducted a study on optimization of mulberry leaves extract by the spray drying technique at drying inlet temperature of 60 °C, the volumetric flow rate of 10 % and outlet temperature of 55 °C by using maltodextrin for the encapsulation. The results indicated that the powder property values, *i.e.*, bulk density and tapped density were found to be 0.345 ± 0.020 to 0.436 ± 0.040 g/ml and 0.427 ± 0.020 to 0.427 ± 0.020 g/ml, respectively. The angle of repose was found to be $32 \pm 0.57^\circ$ to $34 \pm 0.790^\circ$, percentage Carr's Index was found to be 8.66 ± 0.95 and Hausner's ratio was found to be below 1.12 indicating a healthy standard limit. The FTIR (Fourier-Transform Infrared Spectroscopy) study on mulberry leaves extracts confirmed the presence of flavonoids (rutin, quercetin) and alkaloid (1-deoxynojirimycin). Later the encapsulated powder was renewed into anti-diabetic tablets. Further, Tchabo *et al.*,

(2019) [32] suggested two optimal conditions for encapsulation of mulberry leaves extract at a temperature of 140 °C with 0.75 % concentration of sodium carboxymethyl cellulose and 137 °C with 12 % concentration of maltodextrin. The results indicated that the flavonol content (209.10 mg/g), gamma-aminobutyric acid content (3.31 mg/g), cupric ion reducing capacity (43.17 mmol/g of Trolox) and ferric reducing antioxidant power capacity (182.03 mmol/g of Trolox) were observed. The powder properties such as powder recovery (61.85 %), particle density (1.75 g/cc), bulk density (0.35 g/cc), tapped density (0.46 g/cc), wettability time (49.40 seconds), hygroscopicity (18.48 %) and greenness (-4.90) were also significant in the first treatment. However, for the 137 °C with maltodextrin (12 %) was typified by its phenolic acid content (79.22 mg/g), 1-deoxynojirimycin content (13.61 mg/g), 2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (25.37 mmol/g of Trolox), 1,1-diphenyl-2-picrylhydrazyl (74.81 mmol/g of Trolox). The maltodextrin carried powder properties such as particle size (2.24 µm), Hausner ratio (1.06), Carr index (5.48 %), porosity (56.47 %), water solubility index (97.15 %), moisture content (2.75 %) and water activity (0.15) were also noteworthy in this experiment. The other operating parameters *e.g.* feed rate (8 ml/min), aspiration rate (100 %), atomization pressure (600 kpa), feed rate (3 to 10 ml/min to maintain a constant outlet temperature of 80°C) were accustomed.

Several encapsulation techniques have been adopted for mulberry leaves extract. Among them spray drying technique is highly preferred due to economic advantages, uniform particle size, high quality, rapid and high solubility. The overall processing diagram of mulberry leaves is shown in Fig 2.

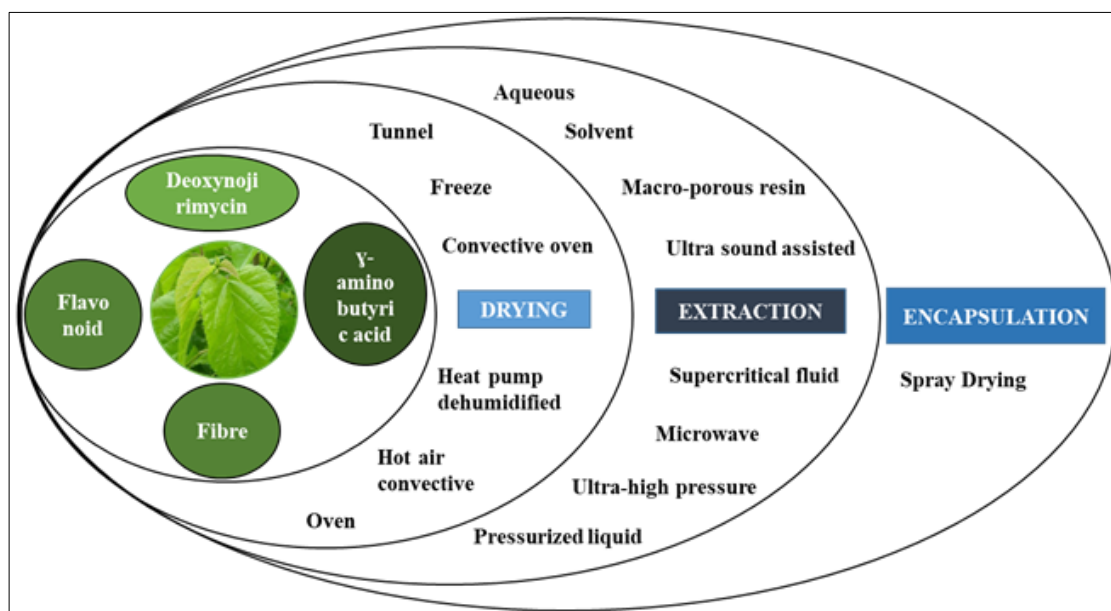


Fig 2: Processing diagram of mulberry leaves

3. Drawbacks in the marketing of mulberry leaves value-added products: The tea is a popular drink that is consumed by all ages. Globally, the total consumption of tea is higher than the consumption of other drinks such as soft drink, coffee and alcoholic beverages (Shahbandeh, 2018) [33]. The mulberry tea prepared from leaf has numerous health benefits compared to normal tea. But the consumer's preferences on mulberry tea over conventional tea are still not so groundbreaking. The slightly vegetal and little bitter in taste could be

the reason. The unavailability of mulberry tea in a ready-to-drink package is also an important point to be noticed. Brewing the mulberry leaves, sometimes is not a practical mode of consumption. Additionally, lack of marketing strategies and implementation of product pricing, promotional activities and distribution systems are the other reasons behind the less popularity of mulberry leaves tea in day to day life. Till today, mulberry tea has not been authoritatively recognized due to standard line for its evaluation.

4. Conclusion

Several research studies have been reported on the nutritional and health benefits of mulberry leaf extract for consumers. However, the literature available for the preparation of mulberry leaves found to be limited. The conventional procedure may not be helpful for the industrial production of processed mulberry leaves and also the effect on nutritional aspects are yet to be explored. This manuscript compiles a few methods for mulberry leaves processing, optimised process conditions and the effects of the different process on nutritional aspects. The application of advance technologies like far-infrared radiation hot air drying or heat pump dehumidifier drying have minimized the bio-active component loss during the drying process. Similarly, microwave, supercritical fluid, high pressure and macroporous resin extraction diminished the solvent requirements, total extraction time and provide high yield compared to conventional extraction methods. Research studies have elucidated the existence of several active molecules in it and those compounds have shown to be effective in the treatment of various diseases thus more research is still required to increase the value-added products of mulberry leaves.

5. Declaration

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Conflict of interest: The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript. Additionally, to the best of our knowledge, the named authors have no conflict of interest, financial or otherwise. The authors declare that they have no conflict of interest.

Availability of data and material: Not applicable.

Code availability: Not applicable.

Authors' contributions: Each named author has substantially contributed to conducting the underlying work and drafting this manuscript.

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