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REVIEW

Vitamins determination by TLC/HPTLC—a mini-review

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Abstract
This review describes the application of thin-layer chromatography (TLC) and high-performance thin-layer chromatography (HPTLC) in the separation and identification of vitamins from their mixtures using different kinds of mobile phases such as isocratic and mixed solvents as well as mobile phases containing various modifiers. TLC has long been used for the separation and semiquantitative determination of biomolecules including vitamins. HPTLC is the modified version of TLC, and it offers the advantages of better resolution, smaller sample size, and lesser volumes of mobile phases. In recent years, the emergence of advanced and fully automated chromatographic techniques such as high-performance liquid chromatography (HPLC) and gas chromatography (GC) has reduced the application of TLC/HPTLC for vitamins analysis. However, due to the inherent simplicity and cost-effectiveness, both TLC and HPTLC continue to be the methods of choice in small laboratories of developing countries. In this short review, the literature survey on TLC/HPTLC of vitamins covering the period 2011−2019 has been encapsulated in a tabular form.

Keywords TLC · HPTLC · Vitamins · Micellar TLC · Silica gel

1 Introduction

Literally, the meaning of vitamins is vital amines that are low molecular weight organic compounds and essential for human health. Out of thirteen compounds recognized as vitamins, nine are water-soluble vitamins (or hydrophilic vitamins) which include thiamine (B1), riboflavin (B2), nicotinamide/nicotinic acid (B3), pantothenic acid (B5), pyridoxine (B6), folic acid (B9), cyanocobalamin (B12), and vitamin C (ascorbic acid). In combination, these are known as "Vitamin B-Complex." The remaining four are fat-soluble (or lipophilic) vitamins which include retinol (vitamin A), tocopherol (vitamin E), calciferol (vitamin D), and anti-hemorrhagic vitamins (vitamin K). These vitamins play specific and vital functions in metabolism. The deficiency or excess of vitamins can cause health problems. These vitamins do not provide energy (calories) directly, but they do help regulate energy-producing processes. Except for vitamins D and K, other vitamins have to be taken from food because they are not synthesized by the body. Deficiencies of vitamins are classified as either primary or secondary. A primary deficiency occurs when an organism does not get enough of the vitamin from the food. A secondary deficiency may be due to an underlying disorder that prevents or limits the absorption or use of the vitamin, due to "lifestyle factors" such as smoking, excessive alcohol consumption, or the use of medications that interfere with the absorption or use of the vitamin. Well-known human vitamin deficiencies involve thiamine (beriberi), niacin (pellagra), vitamin C (scurvy), and vitamin D (rickets). The sources as well as the functions, the physical properties of hydrophilic vitamins and lipophilic vitamins are summarized in Tables 1, 2, and 3 respectively.

1.1 Chromatography

Chromatography is a physical method of analysis in which a mobile phase passes over a stationary phase and the mixture of compounds can be separated into its components. Chromatography has been widely used in pharmaceuticals,

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Table 1 List of sources, name of vitamins, and their functions

Vitamin	Sources	Functions
Vitamin A (retinol)	Fish, egg, carrot, green leafy vegetables, and ripe yellow fruits	Required for growth and development and is important for normal vision
Vitamin B1 (thiamine)	Brown rice, liver, vegetables, oat meal, and oranges	Helps to normalize our heart, nervous system, and muscles
Vitamin B2 (riboflavin)	Banana, green pea, vegetables, and cheese	Helpful in eyes, hairs, and skin growth
Vitamin B3 (nicotinamide)	Cheese, dates, potato, tomato, and fish	Helps to prevent migraine headaches, reduces high blood pressure as well as cholesterol and increases circulation
Vitamin B5 (pantothenic acid)	Fish, mushrooms, and whole grain cereals	Required for the synthesis of many substances and helps to release energy from food
Vitamin B6 (pyridoxine)	Meat, chicken, banana, and cereals	As co-enzyme in amino acid and fatty acid metabolism, helps to reduce kidney stones from forming and build up our immune system
Vitamin B12 (cyanocobalamine)	Meat, chicken, banana, and cereals	As co-enzyme in amino acid and fatty acid metabolism, helps to reduce kidney stones from forming and build up our immune system
Vitamin C (ascorbic acid)	Vegetables and fruits	Ascorbic acid is an antioxidant; it also helps with iron absorption and is important for the health of the immune system
Vitamin D (cholecalciferol)	Fish, liver, and mushrooms	Facilitates calcium and phosphorus absorption
Vitamin E (tocopherol)	Vegetables, fruits, and sunflower seeds	As an antioxidant, helps to protect the cell walls
Vitamin K (phylloquinone)	Green leafy vegetables, yolk, egg, liver and cauliflower	Helps in blood clotting process
Vitamin H (biotin)	Legumes and nuts	Synthesis of fats and proteins, metabolism of carbohydrates

Table 2 Physical properties of water-soluble vitamins

Vitamins	Solubility	Stability
Thiamine (vitamin B1)	Soluble in water; slightly soluble in ethanol; insoluble in ether and benzene	Stable in acidic solution, unstable in light or when heated
Riboflavin (vitamin B2)	Soluble in basic aqueous solution; slightly soluble in water and ethanol; insoluble in chloroform and ether	Unstable in light and heating; slightly unstable in basic solution
Nicotinamide (vitamin B3)	Soluble in water, ethanol, and glycerol	Stable in acidic and basic solutions; stable when exposed to air
Nicotinic acid (vitamin B3)	Soluble in water	Stable in acidic and basic solutions, stable when exposed to air
Pantothenic acid (vitamin B5)	Soluble in water, ethanol, alkali carbonate hydroxide solution, and alkali solution, insoluble in ether	Unstable in acidic and basic solutions; unstable when heated; calcium salt is stable
Pyridoxine (vitamin B6)	Soluble in water, ethanol, methanol, and acetone; insoluble in ether and chloroform	Stable in acid solution; unstable in alkali solution
Folic acid (vitamin B9)	Soluble in alkali solution; slightly soluble in methanol; insoluble in water and ethanol	Stable when exposed to air; unstable when exposed to light
Cyanocobalamine (vitamin B12)	Soluble in water and ethanol; insoluble in ether, acetone, and chloroform	Unstable in alkali and strong acid solutions
Ascorbic acid (vitamin C)	Soluble in water; slightly soluble in ethanol; insoluble in ether	Unstable when exposed to air

biotechnology, natural products, plant analysis, bio-analysis, toxicology, etc.

Depending on the nature of stationary or mobile phases and the mechanism of distribution involved, chromatographic techniques can be classified as (1) high-performance liquid chromatography (HPLC), (2) gas chromatography (GC), (3) thin-layer chromatography (TLC), (4) gel permeation chromatography (GPC), (5) partition

Table 3 Physical properties of fat-soluble vitamins

Vitamins	Solubility	Stability
Retinol (vitamin A)	Soluble in ethanol, methanol, chloroform, ethyl ether, and oil; insoluble in water and glycerol	Easy oxidation and moisture absorption in the air; easy metamorphism in the light; stable in oil
Retinol acetate (vitamin A acetate)/retinol palmitate (vitamin A palmitate)	Soluble in chloroform, ethyl ether, cyclohexane, and petroleum ether; slightly soluble in ethanol; insoluble in water	Easily oxidized in the air; metamorphism in light
β-Carotene	Soluble in chloroform and benzene; insoluble in water, glycerin, propylene glycol, acid, and alkali solutions, ethanol, acetone, and ether	Unstable when exposed to air and light
Ergocalciferol (vitamin D2)	Soluble in alcohol, ether, and chloroform; insoluble in water	Unstable when exposed to air, light, heating, inorganic acids, and aldehydes
Cholecalciferol (vitamin D3)	Soluble in alcohol, ether, acetone, chloroform, and vegetable oil; insoluble in water	Normally, vitamin D3 is more stable than vitamin D2. Stable stored in a vacuum brown ampoule at 4 °C
Tocopherol (vitamin E)/ tocopherol acetate (vitamin E acetate)	Soluble in alcohol, ether, acetone, chloroform, and oil; insoluble in water	Stable in alkali solution and upon heating; slight oxidation in the air; unstable in UV
Phylloquinone (vitamin K1)	Soluble in ether, acetone, and chloroform; slightly soluble in oil and methanol; insoluble in water	Unstable when exposed to light, acid, oxidizers, and halogen

chromatography (PC), (6) countercurrent chromatography (CCC), (7) supercritical fluid chromatography (SCFC), (8) ion-exchange chromatography (IEC) etc.

TLC being a subdivision of liquid chromatography is carried out on a flat surface and hence, it is sometimes referred to as planar chromatographic separation technique. In TLC, the mobile phase (a liquid) migrates through the stationary phase (thin layer of porous sorbent on a flat inert surface) by capillary action.

High-performance thin-layer chromatography (HPTLC) is a sophisticated form of TLC with better and advanced separation efficiency and detection limits. The main difference between HPTLC and TLC is the particle and pore size of sorbents. HPTLC is a flexible, versatile, and economical process in which various stages are carried out independently. The important distinguishable properties of TLC and HPTLC are summarized in Table 4. Similarly, the distinguishable properties of HPTLC and HPLC are also summarized in Table 5.

Table 4 Distinguishable characteristics of TLC and HPTLC

S. No.	Properties	HPTLC	TLC
1	Technique	Automated/instrumental	Manual mean
2	Mean particle size	5–6 µm	10–12 µm
3	Layer thickness	100 µm	250 µm
4	Plate height	12 µm	30 µm
5	Efficiency	High due to smaller particle size	Fewer separations 3–5 cm, 10–15 cm
6	Analysis time	Shorter migration distance and the analysis time is greatly reduced	Slower
7	Solid support	Silica gel for normal phase, C8, and C18 for reversed phase	Silica gel, alumina, and Kieselguhr
8	Sample spotting	Autosampler (syringe)	Manual spotting (capillary/pipette)
9	Sample volume	0.1–5 µL	1–5 µL
10	Shape of sample	Rectangular (6 mm L × 1 mm W)	Circular (2−4 nm diameter)
11	Starting spot's diameter	1–1.5 mm	3–6 mm
12	Separated spot's diameter	2–5 mm	6–15 mm
13	Sample tracks per plate	≤ 36 (72)	≤ 10
14	Separation time	3–20 min	20–200 min
15	Detection limits (florescence)	5–10 pg	50–100 pg
16	Detection limits (absorption)	100–500 pg	1–5 pg

Table 5 Characteristic properties of HPTLC and HPLC

S. No.	Characteristics	HPTLC	HPLC
	Type	Normal-phase chromatography	Reversed-phase chromatography
1	Stationary phase	Solid	Liquid/solid
2	Mobile phase	Liquid	Liquid
3	Conditioning phase	Gas	None
4	Separation by	Adsorption	Partition
5	Results	Detector and eyes	By detector
6	Analysis	Off-line	Online
7	Resolution	Moderate to high	Very high
8	Chromatography system	Open	Closed
9	Separating medium	Planar layer (plate)	Tubular column
10	Analysis in parallel	Yes	No
11	High pressure required	No	Yes
12	Time per sample	1−3 min	2−60 min
13	Post-chromatography derivatization	Simple, possible for every sample, gives additional information	Limited possibilities, cumbersome
14	Sensitivity	Moderate to ultra-high	High to ultra-high
15	Fluorescence data	Possible, built-in	Possible, optional
16	Chromatogram image documentation	Yes, at 254 and 366 nm and visible	No
17	Chromatographic fingerprint	Yes, comprehensive	Yes, but limited
18	Cost per analysis	Low	High
19	Equipment maintenance	Low	High
20	Analysis skill required	Low (TLC) to high (HPTLC)	High to very high

2 Literature survey

In the year 2011, *Ali et al.* [1] published a book chapter on the role of TLC/HPTLC in biomedical applications. A year later, they reviewed the contemporary work on the application of TLC and HPTLC for the analysis and separation of vitamins and amines [2]. Since then, only a few review articles have been reported so far [3–5]. Literature survey also reveals that, compared to the use of TLC/HPTLC, more emphasis has been given to the application of HPLC in the analysis of vitamins as indicative by more than 70 papers reported during 2011−2019 on the use of HPLC for the separation and determination of different types of vitamins. In the present communication, the works conducted during 2011−2019 on the TLC/HPTLC of water-soluble and fat-soluble vitamins are presented in Table 6; it is clear that HPTLC has been more frequently used than normal-phase thin-layer chromatography (NP-TLC) and reversed-phase thin-layer chromatography (RP-TLC) for the separation of water-soluble and fat-soluble vitamins. Table 6 also reveals that more work has been reported on the separation and identification of vitamin C as compared to the other types of vitamins. Modified silica gel layers are also proved more efficient for the researchers in the separation and analysis of different types of vitamins as *Sobanska* reviewed admirably the applications of modified silica gel in TLC [6].

Cimpoiu et al. [7] developed a TLC method in which two different stationary phases (silica gel and cellulose plates), coated side by side, act as gradient adsorbent and a mixture of methanol + benzene + formic acid (6:4:1, *v/v*) as the mobile phase used for the separation of water-soluble vitamins (B6,B3, B2, C, B1, B12, and B9). The experimental values of R_F for different water-soluble vitamins were: B6 = 0.81, B3 = 0.69, B2 = 0.63, C = 0.41, B1 = 0.20, B12 = 0.12 and B9 = 0.05. The developed method is relatively simple and inexpensive enabling the combination of a large variety of stationary and mobile phases for the analysis of various mixtures. Moreover, the spots from a plate developed on the stationary phase can be transformed to the second plate, without the scraping of bands, extraction, and re-spotting. This TLC with stationary phase gradient method was found to be highly applicable for identifying the water-soluble vitamins in the alcoholic extracts of *Hippophae rhamnoides* and *Ribes nigrum.*

Dzema et al. [8] used silica gel modified with hyperbranched (hb) poly(ethyleneimine) (PEI) polymers as the stationary phase and distilled water as the mobile phase for the separation of water-soluble vitamins: thiamine hydrochloride (B1), sodium riboflavin-5-phosphate (B2), pyridoxine (B6), ascorbic acid (C), and cyanocobalamin (B12). The addition of polymers to the mobile phase did not result in changes in the efficiency and selectivity

Table 6 Summary of the work done during 2011−2019 on the use of TLC/HPTLC for the analysis of water- and fat-soluble vitamins

S. No.	Stationary phase	Mobile phase	Remarks	Reference
1	Precoated aluminum-backed silica gel G 60 F_{254} HPTLC plate	A mixture of ethanol, chloroform, acetonitrile, toluene, ammonia, and water (7:4:4.5:0.5:1:1, *v/v*)	The proposed densitometry−TLC method was valueable for detecting B group vitamins at 254 nm. The R_F values for vitamins follow the trend: B6 (0.85) > B2 (0.60) > B12 (0.46) > B1 (0.36)	[9]
2	Kieselgel 60 F_{254}	Chloroform + ether (9:1, *v/v*)	Quantification of vitamin D3 in fish at 280 nm without derivatization	[10]
3	Silica gel 60 F_{254} TLC plates	A mixtures of ethanol + glacial acetic acid + toluene (5.5:1:1.5, *v/v*) and ethyl acetate + toluene + acetone (4.5:4:1, *v/v*)	The proposed HPTLC−densitometric method consists of aluminum-backed silica gel 60 F_{254} TLC plates as the stationary phase and mixtures of ethanol + glacial acetic acid + toluene and ethyl acetate + toluene + acetone in different volume ratios as the mobile phases for the selective separation of ascorbic acid and gallic acid, respectively. This proposed method was found the most suitable for the quantitative estimation of ascorbic acid and gallic acid in herbal medicines	[11]
4	HPTLC silica gel G 60 F_{254} plates	A mixture of methanol, ethanol, isopropanol, and water (75:5:5:15, *v/v*)	The developed TLC system was found to be the most useful for the identification of vitamin K homologues including phylloquinone (PK, vitamin K1), menaquinone-4 (MK-4, vitamin K2), and menaquinone-7 (MK-7, vitamin K2). The quantification of vitamin K homologues was done by densitometric absorbance at 254 nm. The limits of detection and quantification were 0.19–0.85 and 0.76–2.5 µg/band, respectively	[12]
5	Silica gel 60 F_{254} TLC plates	A mixture of *n*-butyl alcohol, 70% aqueous ethylene glycol, and ethyl acetate (5:2:3, *v/v*)	The proposed analytical method was used for efficient separations of amino acids, vitamins, and sugars from their multicomponent mixtures. This method was also found the most applicable for the identification of methionine in Beplex Forte and thiamine as well as ascorbic acid in orange juice with preliminary separation on HPTLC plate from other components	[13]
6	Silica gel 60 F_{254} TLC plates	A mixture of ethyl acetate + methanol + water + acetic acid (15:10:2:1, *v/v*)	HPTLC–densitometric analysis was performed on 10 × 20 cm aluminum-backed plates coated with 0.2 mm layers of silica gel 60 F_{254} as the stationary phase and a mixture of ethyl acetate + methanol + water + acetic acid (15:10:2:1, *v/v*) as the mobile phase for the simultaneous quantification of diosmin, hesperidin, and ascorbic acid at microgram level	[14]
7	Silica gel	A mixture of dichloromethane, acetone, glacial acetic acid (4:3:3, *v/v*)	The experiment was performed on silica gel plate, previously activated at 105 °C. The activated plate was spotted with standard and ayurvedic formulation. The elution was done by using mobile phase consisting of dichloromethane + acetone + glacial acetic acid (4:3:3, *v/v*), and the eluted spots were detected by using iodine in a closed chamber. The R_F values of ascorbic acid and gallic acid were found to be 0.77 and 0.84, respectively. This method was found applicable to identify and quantify the ascorbic acid in the presence of gallic acid in ayurvedic herbal formulation	[15]

Table 6 (continued)

S. No.	Stationary phase	Mobile phase	Remarks	Reference
8	Silica gel 60 F_{254} TLC plates	A mixture of ethyl acetate + methyl isobutyl ketone + formic acid + glacial acetic acid + water in different proportions by volume	The proposed TLC–densitometric method consisting of silica gel 60 F_{254} TLC as the stationary phase and a mixture of ethyl acetate + methyl isobutyl ketone + formic acid + glacial acetic acid + water in different proportions (20:12:2.8:1.2:2, *v/v*) as the mobile phase was found to be the most suitable for the simultaneous determination of ascorbic acid (AA) and rutin (RU) in their mixtures as well as in pharmaceutical formulations without prior separation. The plates were scanned at 276 and 370 nm for AA and RU, respectively, using a deuterium lamp, absorbance mode at 3 mm × 0.45 mm slit dimension, and scanning speed of 20 mm S^{-1}	[16]
9	Silica gel 60 $RP18WF_{254}$	A mixture of methanol + water (3:7, *v/v*)	HPTLC−densitometric technique in reversed-phase system was used for the quantitative determination of nicotinamide (as vitamin PP) in selected pharmaceutical formulations (tablets and injection solution) at 200 nm in absorbance mode	[17]
10	Silica gel 60 F_{254} TLC plates	A mixture of methanol + ethyl acetate + ammonia (25%) (13:77:10, *v/v*)	This TLC–densitometry system was used to determine the pyridoxine, nicotinamide, and caffeine in the energy drink sample. Detection and quantification limits of pyridoxine, nicotinamide, and caffeine were reported	[18]
11	TLC plates coated with silica gel 60 F_{254}	A mixture of methanol + chloroform + ethyl acetate + glacial acetic acid + ammonia solution (6:2:2:0.5:0.1, *v/v*)	The proposed TLC−densitometric method was used for the determination of vitamin E (α-tocopherol acetate) and vinpocetine in the presence of vinpocetine alkaline-induced degradation product in bulk powder and in pharmaceutical formulation without preliminary separation steps using densitometric absorbance mode at 235 nm	[19]
12	TLC plates coated with silica gel 60 F_{254} pre-washed with isopropanol	A mixture of chloroform + ethyl acetate (1:1, *v/v*)	Vitamin C was quantitatively estimated in fruit juice using densitometric absorbance mode at 510 nm	[20]
13	TLC plates coated with silica gel 60 F_{254}	A mixture of toluene + ethyl acetate + chloroform (10:1:2, *v/v*)	This HPTLC system was used for the simultaneous quantification of co-enzyme Q10 (ubiquinone) and α-tocopherol in bulk and capsule dosage form using densitometric absorbance mode at 280 nm. The R_F values for co-enzyme Q10 and α-tocopherol were 0.77 and 0.87 respectively	[21]
14	Silica gel 60 F_{254} TLC plates	A mixture of methanol + isopropanol + water + acetic acid (9:0.5:0.5:0.2, *v/v*)	This TLC−densitometric method was used for the determination of folic acid in the presence of its degradation products using silica gel 60 F_{254} plates as the stationary phase and a mixture of different solvents (methanol + isopropanol + water + acetic acid, 9:0.5:0.5:0.2, *v/v*) as the developing system. This method was found suitable for the detection and determination of folic acid (FOL) in the presence of its degradation products without sample pre-treatment	[22]

Table 6 (continued)

S. No.	Stationary phase	Mobile phase	Remarks	Reference
15	Silica gel 60 F_{254} plates	A mixture of chloroform + acetone + trifluoroacetic acid (6.5:3.5:0.30, *v/v*)	The proposed method was used for the determination of ascorbic acid, paracetamol, and guaifenesin in the presence of their toxic impurities by using silica gel 60 F_{254} plates as the stationary phase and a mixture of chloroform + acetone + trifluoroacetic acid (6.5:3.5:0.30, *v/v*) as the mobile phase. The detection was done by using UV at $\lambda = 254$ nm. The proposed method has the advantage over the reported RP-HPLC method that it offered high resolution between the drugs and their known impurities	[23]
16	Silica gel 60 F_{254} plates	A mixture of ethyl acetate + acetone + water + formic acid (10:6:2:2, *v/v*)	This HPTLC system consisting of silica gel 60 F_{254} plates as the stationary phase and a mixture of ethyl acetate + acetone + water + formic acid (10:6:2:2, *v/v*) as the mobile phase was the most appropriate for the identification of ascorbic acid (AA) and gallic acid (GA) in the dried freeze pomegranate fruit juice. The spots detected using densitometer at a wavelength of 254 nm showed R_F 0.54 and 0.83 for AA and GA, respectively	[24]
17	Silica gel 60 F_{254} plates	A mixture of acetone + toluene + water + glacial acetic acid (26:4:4:1, *v/v*)	The proposed HPTLC system performed on silica gel 60 F_{254} plates as the stationary phase and a mixture of acetone + toluene + water + glacial acetic acid in different proportions by volume as the mobile phase has been used for the analysis of ascorbic acid in the presence of their degradation products for the assessment of stability of ascorbic acid in *Hibiscus Sabdariffa* products. The detection of spot was done using densitometer at a wavelength of 269 nm. This method was highly specific because it was able to separate all degradants without being interfered by other constituents present in the *H. sabdariffa* juice	[25]

parameters of analytes because of the strong sorptive retention of the polymers on the silica surface (due to electrostatic and hydrogen bond interactions), which prevented the modifier from moving along the TLC plate. The influence of polymer structure (degree of substitution of PEI terminal amino groups with oligosaccharides and molecular weight of dendritic core [5 or 25 kDa]) as well as the content of PEI-OS (polyethylenimine oligosaccharides) in the stationary phase and a method of modification of the stationary phase on the efficiency of vitamin and amino acid determination and on the enantioselectivity factors of β-blockers separation were investigated. As for vitamin B6, an increase in retention and decrease in efficiency were observed for the case of using polymers, having less dense oligosaccharide shells as components of the stationary phase. The increase in the analytes affinity to the polymer-modified stationary phase points to the interaction between pyridoxine and the polymers.

3 Conclusion and future prospects

The literature survey reveals that both isocratic and mixed solvents are commonly used as mobile phases for the separation of different vitamins. None of the studies during 2011−2019 showed the use of surfactants or ionic materials as impregnating agents or mobile phase modifiers. Both TLC and its refined version, HPTLC, are simple and inexpensive techniques for the analysis of biomolecules including vitamins, particularly in the poorly funded laboratories of developing countries. The advantages of HPTLC are semi-automation, greater resolution, and reduced consumption of mobile phase. Although TLC and HPTLC cannot reach the resolution and detection limit of HPLC, the former techniques provide sufficient resolving power for most of the sample types. There is a need of developing novel coating materials, modifiers, detecting reagents, and environment-friendly mobile phases for the efficient utilization of these simple and low-budget chromatographic techniques for the separation and determination of biomolecules including different types of vitamins. Figure 1 describes the relative magnitude (%) of published papers on different types of vitamins using HPTLC/TLC and Fig. 2 represents the relative magnitude (%) of the number of papers published on water-soluble vitamins (B-complex and vitamin C) during 2011−2019.

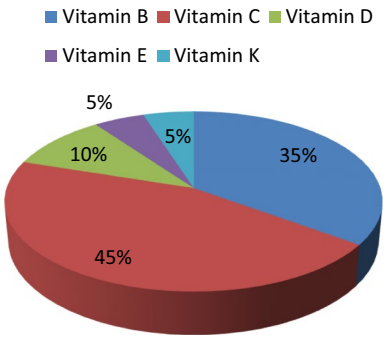

Fig. 1 Representation of the magnitude (%) publications of different types of vitamins during 2011−2019

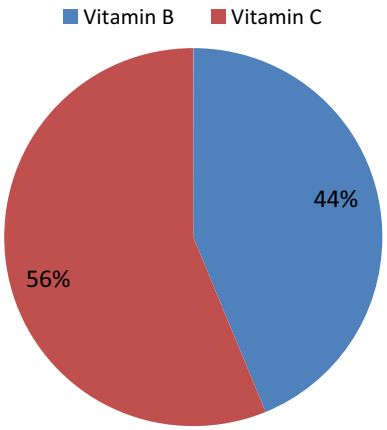

Fig. 2 Representation of the magnitude (%) of publications of water-soluble vitamins during 2011−2019

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