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Research Article

Physicochemical evaluation of Olive (*Olea europea*) fruit, halophyte (*Salicornia herbacea* L) plant salts and bamboo (*Bambos arundinaceae*) silica salts based effervescent tablets with promoting edible organic acids and carbonates

Ahamed S. Wasim
College of Horticulture, Mojerla, Sri Konda Laxman Telangana State Horticultural University (SKLTSHU), Wanaparthy (Telangana), India
Shankaraswamy Jadala*
College of Horticulture, Mojerla, Sri Konda Laxman Telangana State Horticultural University (SKLTSHU), Wanaparthy (Telanagana), India
Sathish Gokenapally
Post Graduate Institute for Horticultural Sciences, Sri Konda Laxman Telangana State Horticultural University (SKLTSHU), Mulugu (Telangana), India
Nagaraju Kattula
College of Horticulture, Mojerla, Sri Konda Laxman Telangana State Horticultural University (SKLTSHU), Wanaparthy (Telangana), India
Sridevi Gajula
Babu Jagjivan Ram Agricultural College, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Sircilla (Telangana), India

*Corresponding author. E-mail: shankara.swamy@gmail.com

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Abstract
Maintainance of extracellular volume and water balance is important in cellular metabolism and these properties confer to sodium profile, but overconsumption of sodium causes risk to health. The present study aimed to develop and evaluate fast-dissolving effervescent tablets using a novel two-step wet granulation method, incorporating Olive (*Olea europaea)*, halophyte marsh plant (*Salicornia herbacea* L.) and bamboo silica salts natural ingredients and edible organic acids viz. citric acid, malic acid, tartaric acid, apple cider vinegar powder, fumaric acid and alkalizing agents like sodium bicarbonate, anhydrous potassium carbonate, anhydrous sodium carbonate, potassium sulphate dodecahydrate as active ingredients to enhance bioavailability and dissolution. During the process, all active ingredients were milled separately and sifted through a number 40 mesh sieve, followed by blending for 10 min to create uniform wet mass and further, sieved through number 20 mesh to produce granules. Finally, the dried granules of the composition according to formulations were compressed into tablets with 12 mm diameter using a single punch tablet punching machine. The formulations adhered to pharmacopoeial quality standards, displaying favorable mechanical and physical properties. The results revealed that the effervescent granules in all the formulations exhibited excellent flow properties with Angle of Repose, Hausner's ratio and compressibility index in the ranges of 26.10°-29.52°, 1.07-1.12 and 6.12%-10.51% respectively. Formulations F1 and F3 emerged as the most effective, with friability <0.5%, water content <0.05%, effervescence time <2.5 min and excellent solubility on the Likert scale. The findings open avenues for further research into effervescent technology and its application in drug delivery systems.

Keywords: Effervescent tablets, Flow properties, Natural ingredients, Solubility, Wet granulation method

INTRODUCTION

In recent years, there has been a growing emphasis on developing novel drug delivery systems to improve patient compliance and therapeutic outcomes. Drug delivery technologies have positively impacted the effectiveness of treatment in various ways, such as improving therapeutic efficiency, minimizing toxicity, promoting patient adherence, and facilitating the development of innovative medical treatments (Gao *et al.,* 2023).

Among these, fast-dissolving effervescent tablets have emerged as a promising solution, offering rapid drug dissolution and enhanced bioavailability. It emerges as a promising and viable option for delivering medications to elderly individuals, children, and critically ill patients who encounter challenges in swallowing conventional tablets. This, in turn, enhances overall patient adherence to the prescribed treatment regimen (Gupta, 2022). Conventional tablets and capsules, necessitating consumption alongside an 8-ounce glass of water, may present obstacles for those with difficulty swallowing solid oral medications. Fast-dissolving tablets are uniquely crafted to swiftly dissolve or disintegrate within a minute (Parveen and Ramu, 2023). Fast-dissolving effervescent tablets have gained popularity due to their convenience, particularly for individuals with difficulty swallowing conventional tablets or those seeking on-the-go medication options. Administering therapeutics through synthetic polymers poses challenges such as toxicity, immunogenicity and diminished bioavailability post-administration (Malik *et al.,* 2022). The integration of natural ingredients in pharmaceutical formulations aligns with the contemporary trend toward green and sustainable practices in the pharmaceutical industry.

Recognized as a renowned medicinal herb, *Salicornia herbacea* L. is acknowledged for its remarkable impact on blood sugar control. A study substantiating the effectiveness of *S. herbacea* L. revealed that incorporating it into the diet decreased body weight and lowered blood glucose levels (Lee *et al.,* 2015). *S. herbacea* L. is recognized as a functional ingredient, containing 38.5 g of dietary fiber per 100 g. Additionally, it is rich in essential minerals, including choline, betaine, sodium, phosphorus, calcium, potassium and magnesium. This composition highlights the potential utilization of *S. herbacea* L. as a valuable functional food ingredient (On *et al.,* 2023; Jung *et al.,* 2009). Olive salt, obtained from olives, is rich in polyphenols and antioxidants. The abundant presence of phenolic compounds in olive derivatives is closely tied to their nutritional and medicinal attributes. These compounds are recognized for imparting distinct organoleptic and antioxidant properties. Olive polyphenols, in particular, assume a significant role in human diet and well-being, acting primarily as antioxidants and scavengers of free radicals. Given these characteristics, they hold promise as viable sources of natural antioxidants for the food industry, potentially contributing to creating safe food products. Furthermore, the well-documented lower incidence of cardiovascular disease in the Mediterranean region is, in part, linked to the consumption of olive products (Uylaşer and Yildiz, 2014).

Emerging scientific findings reveal that extracts derived from bamboo exhibit a range of beneficial properties, including antioxidant and free radical scavenging capabilities and antimicrobial, anti-aging, and cardioprotective attributes (Das, 2019). Bamboo salt is known for its wide-ranging therapeutic benefits, effectively addressing ailments from viral infections and dental plaque to diabetes and circulatory issues. It also aids in cancer therapy, soothes inflammatory conditions, alleviates symptoms of allergic rhinitis, and protects against the hearing damage often caused by chemotherapy treatments like cisplatin. This versatile natural remedy underscores the healing power of traditional substances in modern health care, offering relief and support across a spectrum of conditions (Kim *et al.,* 2012; Kim *et al.,* 2013). Bamboo silica salt is a versatile nutrient with wide-ranging benefits for bone health, skin, hair, and nail vitality, joint mobility, detoxification, cardiovascular wellness, and immune system support. Bamboo silica in the diet or supplement regimen could contribute to overall health and well-being (Martin, 2013).

The integration of natural ingredients in pharmaceutical formulations aligns with the contemporary trend toward green and sustainable practices in the pharmaceutical industry. The present study aimed to examine the development of fast-dissolving effervescent tablets comprising salts from *Salicornea harbacea*, olive, silica from bamboo, and edible organic acids and alkalizing agents. The research delves into the formulation of effervescent tablets with varying compositions and identifies the optimal formulation by evaluating various physicochemical parameters.

MATERIALS AND METHODS

Research tools and materials

The tools used in the study were digital electronic balance (Kerro), Bulk density apparatus (Sisco), Sieve Shaker (Bio Technics, India), Monsanto hardness apparatus (Yamto), Friability testing apparatus (Electro lab), Hot air oven (Yamto), pH meter (Vanira), digital Vernier calliper (Yuri), sieves (Scientific Engineering Corporation), glassware (Borosil), tablet compression machine (Best Scientific Co.).

Polyethylene glycol (PEG) 6000, citric acid, tripotassium citrate monohydrate, sodium bicarbonate, potassium carbonate anhydrous, pearlitol, PVP K30, malic acid, L-leucine, adipic acid, sodium carbonate anhydrate, tartaric acid and fumaric acid were obtained from SD Fine Chem. Limited, Mumbai and Apple cider vinegar powder procured from Chioma®, Yerba mate, South America.

Active ingredients used in the formulation included Salicornia Herbacea salt (Nature's Treasure, Korea), potassium sulfate dodecahydrate (Vipin Kala Namak Factory (p) Ltd., Ghaziabad, Uttar Pradesh, India), Olive salt (Al Harb, India) and Bamboo silica (Saltify, Nagpur, India).

Preparation of effervescent tablets by two-step wet granulation method

The production of fast-dissolving effervescent tablets using a two-step wet granulation method involved accurately measuring specific quantities of acid, base, and other active ingredients. The detailed composition of these ingredients is provided in Tables 1 and 2. Initially, the acid and base components were milled separately, sifted through a Number 40 mesh sieve, and blended for 10 minutes. A uniform wet mass of acid and base was then obtained separately by adding the binder solution and blending for a further 15 minutes. Subsequently, the wet mass was passed through a Number 20 mesh sieve to produce granules of consistent size. These granules were dried in an oven at 55 °C for 60 minutes and were subsequently re-sieved through a Number 20 mesh sieve to ensure homogeneity. The blended materials were then stored in a triple-laminated aluminum moisture barrier bag until needed. The acid and base granules were thoroughly mixed with the lubricant before the compression step. The granule mixture was compressed into tablets with a manually operated single-punch tablet punching machine (Best Scientific Co, India) equipped with a 12 mm punch set. Finally, the resulting tablets were dried in a hot air oven (Yamto) with air circulation at 50 °C for 80 minutes after being wrapped in aluminum foil and packaged in HDPE plastic bottle containers. The prepared granules and compressed effervescent tablets were evaluated for various pre-compression and post-compression parameters.

Evaluation of pre-compression characteristics

The following were the essential flow properties and compressibility parameters monitored during granulation:

Bulk density (ρb): Bulk density was measured by pouring a 100 g sample of powder mixture into a 250 ml graduated cylinder using a glass funnel, with the volume recorded and the bulk density was calculated using the following formula (Monton *et al*., 2014).

$$\rho\ bulk\ = \frac{m}{V} \qquad \text{Eq. 1}$$

Where, *m* is the mass of granulation and *V* is the volume of granulation (untapped)

Tapped density (ρt): The tapped density was determined by subjecting the same cylinder with the powder mixture to 100 strokes on a tapped density tester (Sisco) until the volume stabilized, and then the tapped density was calculated using the following formula (Monton *et al.,* 2014).

$$\rho\ tapped = \frac{m}{V} \qquad \text{Eq. 2}$$

Where, m is the mass of granulation and V is the volume of granulation (tapped)

Hausner's ratio: Hausner's ratio is calculated as the ratio of tapped density to bulk density. The standard Flowability scale for Hausner's ratio is provided in Table 3. The Hausner's ratio was determined using the following formula (Patel *et al.,* 2012).

$$\text{Hausner's ratio} = \frac{\rho\ tapped}{\rho\ bulk} \qquad \text{Eq. 3}$$

Compressibility index (%): The powder flow, also referred to as Carr's index percentage compressibility, was measured indirectly using bulk densities. The standard Flowability scale for Compressibility index is given in Table 3. Carr's index for each formulation was calculated using the following equation (Patel *et al.,* 2012).

$$\text{Carr's index} = \frac{\rho\ tapped - \rho\ bulk}{\rho\ tapped} \times 100 \qquad \text{Eq. 4}$$

Angle of Repose (°): The Angle of Repose was measured using the fixed funnel method, where granules were poured through a funnel positioned at a height H and forming a conical pile of radius R on a flat surface, until they touched the funnel tip. The standard Flowability scale for Angle of Repose is given in Table 4. The Angle of Repose was calculated as per Shabbir *et al*

Table 1. Ingredients used for formulating effervescent tablets

Chemical	Category
Citric acid	Acidifying agent
Tripotassium citrate monohydrate	Salt
Sodium bicarbonate	Alkalizing agent
Potassium carbonate anhydrous	Alkalizing agent
Pearlitol	Diluent
PVP K30	Binding agent
Malic acid	Acidifying agent
L-Leucine	Lubricant
Adipic acid	Acidifying agent
Sodium carbonate anhydrates	Alkalizing agent
Potassium sulphate dodecahydrate	API
Salicornea herbacea salt	API
PEG 6000	Lubricant
Tartaric acid	Acidifying agent
Apple cider vinegar powder	Acidifying agent
Fumaric acid	Acidifying agent
Olive salt	API
Bamboo silica	API

Table 2. Composition of each formulation in effervescent tablet preparation

Ingredients (mg)	F1	F2	F3	F4
Citric acid	13	0	0	0
Tripotassium citrate monohydrate	46	40	63	37
Sodium bicarbonate	46	40	62	50
Potassium carbonate anhydrous	33	55	33	46
Pearlitol	30	48	30	50
PVP K30	0.5	1	1	1
Malic acid	13	0	0	0
L-Leucine	2	5	6	5
Adipic acid	16	22	0	0
Sodium carbonate anhydrates	50	57	54	56
Potassium sulphate dodecahydrate	1	6	0	0
Salicornea herbacea salt	1.5	7	5	7
PEG 6000	4	8	6	8
Tartaric acid	13	0	17	0
Apple cider vinegar powder	13	0	18	0
Fumaric acid	16	0	0	26
Olive salt	1.5	11	5	10
Bamboo silica	0.5	0	0	4

All Quantity in mg/tablet. Compression weight (mg) of tablet is 300mg

(2021).

$$Tan\,\theta = \frac{H}{R} \qquad \text{Eq. 5}$$

Evaluation of post-compression tablet characteristics

Hardness (N): The Monsanto hardness tester (Yamto) was utilized to assess the hardness of the effervescent tablet. The force required to fracture the tablet was recorded, and the initial zero force reading was subtracted from it (Aslani and Fattahi, 2013).

Friability (%): The friability of 20 tablets was tested by weighing them before and after a 4-minute run in a friabilator at 25 rpm, with the weight difference used to calculate their friability (Aslani and Sharifian, 2014).

Friability% =

$$\frac{Weight\ of\ tablets\ before\ test - Weight\ after\ test}{Weight\ of\ tablets\ before\ test}\ x\ 100 \qquad \text{Eq. 6}$$

Water content (%): Ten tablets from each formulation were kept in a desiccator with activated silica gel for 4 hours, after which their water content percentage was calculated (Aslani and Eatesam, 2013).

Water content % =

$$\frac{Weight\ before\ drying - Weight\ after\ drying}{Weight\ before\ drying}\ x\ 100 \qquad \text{Eq. 7}$$

Effervescence time (sec): The effervescence time of a tablet was determined by measuring how long it took to dissolve in water from the moment of immersion until full dissolution (Aslani and Eatesam, 2013).

Solubility (Likert Scale): A Likert scale was used to assess volunteers' perceptions of effervescent tablet solubility in water, asking them to rate effervescence attributes from 1 (very poor) to 5 (excellent) as shown in Table 5. Participants evaluated the effervescence and dissolution qualities, with their ratings used to measure overall satisfaction with the tablet's effervescence (Aslani and Fattahi, 2013).

Data analysis

All measurements were carried out in triplicate, statistical analysis was performed using ANOVA, and differences were considered statistically significant for p values < 0.5 and 0.1. Different letters in the figures designate values with a significant difference among effervescent tablet formulations and decontamination treatments.

RESULTS AND DISCUSSION

Evaluation of pre-compression characteristics

Bulk density (g/cm^3)

The results of the data on bulk density of dry granules at pre compression in different formulations were measured and the results are shown in Table 6. The results revealed that F2 recorded a significant maximum (0.485 g/cm^3) bulk density over the rest of the formulations. The F3 had the second highest (0.483 g/cm^3) bulk density, followed by F4 (0.460 g/cm^3). The F1 had the lowest (0.442 g/cm^3) bulk density, indicating that the mean diameter of the particles in the granules of F1 had the lowest (330.448 µm) mean particle diameter distribution compared to other formulations, which represented that bulk density depends on both the density of powder particles and the spatial arrangement of particles in the powder bed. Very small particles were too cohesive and thus formed more clusters, which led to low bulk density in powder beds. Lighter granules compact into stronger tablets over a range of compaction forces, and the effect is attributed to greater intergranular bonding (Khan and Musikabhumma, 1981).

Tapped density (g/cm^3)

The data on tapped density of granules at pre-compression in different formulations were measured,

Table 3. Flowability Scale for Compressibility index and Hausner's ratio

Compressibility Index (%)	Flow character	Hausner Ratio
≤10	Excellent	1.00–1.11
11–15	Good	1.12–1.18
16–20	Fair	1.19–1.25
21–25	Passable	1.26–1.34
26-31	Poor	1.35–1.45
32–37	Very poor	1.46–1.59
>38	Very, very poor	>1.60

Table 4. Characteristics of material flow and associated Angles of Repose

Flow property	Angle of Repose (°)
Excellent	25–30
Good	31–35
Fair—aid not needed	36–40
Passable—may hang up	41–45
Poor—must agitate, vibrate	46–55
Very poor	56–65
Very, very poor	>66

Table 5. Numeric and descriptive 5 Point Likert scale

Descriptive scale	Numeric-scale
Very poor	1
Poor	2
Average	3
Good	4
Excellent	5

and the results are shown in Table 6. It was observed that the formulations F2 (0.543 g/cm^3) and F3 (0.522 g/cm^3) recorded significant maximum tapped density over the rest of the formulations. F4 and F1 had the lowest (0.490 g/cm^3) tapped density, indicating that high tapped density indicated a greater mass held in the blender, leading to improved packaging efficiency and higher drug loading due to increased fines content. Hence, maintaining a consistent tapped density and unchanged flow energy measurements reduces variability in raw material properties from batch to batch. As drug load increases, tapped density also rises and this property offers an advantage in tableting by reducing the fill volume of the dye. Tapped density is a quality indicator for raw materials and influences flow behaviour (Janssen *et al*., 2023).

Hausner's ratio

The experimental findings regarding Hausner's ratio are presented in Table 7. In this study, all formulations exhibited Hausner's ratios ranging from 1.07 to 1.12, suggesting good flow properties of granules. The ratio decreased as particle size increased, highlighting less significant inter-particle forces and improved flow with larger particles. This inverse relationship between particle size and cohesiveness is pivotal for understanding powder behavior. According to the United States Pharmacopoeia (USP31-NF26, 2008), the flow behavior of formulations F4 (1.07), F3 (1.08), F1 (1.11) was categorized as excellent, and F2 (1.12) as good, attributing these results to the reduced interparticulate friction among coarse, spherical particles compared to flaky ones with higher cohesion. Below a Hausner's ratio of 1.25, the effect of particle size on flow becomes more pronounced, serving as a predictive marker for powder flow by assessing friction between particles (Kalman, 2021). This study demonstrates the critical role of particle size and shape in powder flowability, which is crucial for pharmaceutical manufacturing and product quality.

Compressibility index (%)

The experimental findings regarding Compressibility index are presented in Table 7. The Compressibility Index for various formulations ranged from 6.12%-10.51%, indicating excellent flow properties. These results can be elucidated by the decrease in granule porosity, which, in turn, led to a reduction in granule fragmentation, resulting in decreased granule compressibility (Fayed *et al*., 2017).

The Compressibility index and Hausner's ratio, key indicators of powder flowability, vary with granulation methods rather than intrinsic powder properties. In the present study, different ingredient combinations did not notably affect the flow properties of the blends, with compressibility index values ranging from 6.12% to 10.51%, indicating acceptable flow for manufacturing. No significant differences in compressibility indices among formulations suggest uniform flow characteristics across the blends. The slight decrease in the compressibility index for Formulation 4 could be attributed to the specific inclusion of Bamboo silica, aligning with findings by Bejugam *et al*. (2009) and supported by Pandey *et al*. (2013); Johansson and Alderborn (2001), who reported similar effects in granules with high density and low porosity.

Angle of Repose (°): The data on the Angle of Repose of dry granules at pre-compression in different formulations were measured, and the results are shown in Table 7. The Angle of Repose for dry granules pre-compression in various formulations ranged from 26.10° to 29.52°, indicating excellent flow properties as per the United States Pharmacopoeia (USP31-NF26, 2008) standards. Formulations F4 and F1, incorporating bamboo silica and fumaric acid, among other ingredients, exhibited the best flow characteristics, with the lowest Angles of Repose (26.10° for F4 and 26.56° for F1). These findings suggest that flowability improves with increased granulate content, likely due to larger, more spherical particle shapes (Agrawal and Naveen,

2011). Moreover, the superior flowability in some formulations was linked to the use of minimal alcohol and PVP as binders in the wet granulation process, corroborating with Aslani and Eatesam (2013), who noted enhanced flow properties through wet granulation.

Evaluation of post-compression tablet characteristics

Hardness (N)

The data on the hardness of the formulated effervescent tablets is presented in Table 8. In the study on effervescent tablets produced via a two-step wet granulation method, hardness measurements varied between 41.44 N and 64.07 N. F2 exhibited the highest hardness (64.07 N). In comparison, F1 had the lowest (41.44 N), suggesting that tablet firmness increases with compression force up to a point, beyond which hardness decreases due to the reduced plastic deformation capacity of the material (Late *et al.,* 2009). This reduction at higher compression forces might be linked to enhanced particle-to-particle contact, increasing the mechanical strength initially before leading to a decline (Adeleye *et al.,* 2015). Moreover, tartaric acid was found to soften tablets due to its hygroscopic nature, whereas increased sodium bicarbonate levels hardened them, impacting effervescent tablet hardness (Herlina *et al.,* 2020).

Friability (%)

The data on the friability of the formulated effervescent tablets were measured, and the results are shown in Table 8. The maximum friability was 0.41% in Formulation 2 (F2). The minimum friability of the formulation was 0.18% in Formulation 1 (F1). The positive impact of compaction pressure on decreasing friability is directly linked to its influence on the mechanical strength of tablets. As commonly observed, when a tablet is stronger, its friability tends to be lower (Late *et al*., 2009). This is because it becomes more challenging to dislodge individual particles from a sturdy tablet through mechanical impact during friability testing (Osei-Yeboah and Sun, 2015). However, if the compaction pressure exceeds a certain threshold and triggers overcompression, the tablet's friability may increase at higher pressures (Chowhan *et al*., 1992). Elevating compression pressure leads to a decrease in the friability percentage for all tablets. This can be attributed to the fact that applying high pressure results in excellent compatibility and increased strength (Mousa Al-Ibraheemi *et al*., 2019).

Water content (%)

The data on the water content of the formulated effervescent tablets is shown in Table 8. The maximum water content of the F2 Formulation was 0.055%, and the minimum of 0.017% was that of F1 formulation. Water content for all the formulations was acceptable according to British pharmacopoeia, i.e. < 0.1% (Aslani and Eatesam, 2013). Generally, the enhanced stability of these effervescent tablets (ETs) might result from the effective PVP coating applied to the surfaces of two different granule types used in ETs. This coating creates a physical barrier that separates the acid and alkali sources, effectively preventing the acid-alkali reaction due to the reduced moisture affinity of the effervescent mixtures. A rise in PVP's molecular weight may lead to higher surface viscosity, effectively blocking moisture infiltration from the surroundings into the effervescent agents (Zheng *et al*., 2019).

Effervescence time (sec)

The data on the effervescence time of the formulated effervescent tablets is shown in Table 8. The effervescence time of tablets ranged from 114.25-216.50 sec. Formulations F2 (216.50 sec), F4 (207.25 sec), and F3 (144.25 sec) exhibited longer effervescence times due to higher moisture content, while F1 had the shortest time (114.25 sec) due to lower moisture. These effervescent tablets met the European Pharmacopoeia standard of less than 5 minutes, aligning with effervescent tablets prepared for appropriate delivery of mango, cactus fruit and chlorella powder Sun *et al.* (2020). However, European Pharmacopoeia believes fast-disintegrating effervescent tablets should disintegrate

Table 6. Bulk density (g/cm^3) and Tapped density (g/cm^3) properties of granules in different formulations

Treatment	Bulk density (g/cm^3)	Tapped density (g/cm^3)
Formulation 1	0.442^{a}	0.490^{b}
Formulation 2	0.485^{c}	0.543^{a}
Formulation 3	0.483^{ab}	0.522^{a}
Formulation 4	0.460^{bc}	0.490^{b}
Mean	0.467	0.511
CV	3.179	3.458
SE(m)	0.007	0.009
CD at 5% level	0.023	0.027
CD at 1% level	0.032	0.038

Table 7. Hausner's ratio, Compressibility index (%) and Angle of Repose (°) of different formulations

Treatment	**Hausner's ratio**	**Compressibility index** (%)	**Angle of Repose** (°)
Formulation 1	1.11	9.56	26.56^{b}
Formulation 2	1.12	10.51	29.52^{a}
Formulation 3	1.08	7.60	27.47^{ab}
Formulation 4	1.07	6.17	26.10^{b}
Mean	1.094	8.445	27.414
CV	4.444	48.038	5.327
SE(m)	0.024	2.028	0.730
CD at 5% level	NS	NS	2.250
CD at 1% level	NS	NS	3.154

Table 8. Evaluation of hardness, friability, water content, effervescence time and solubility of effervescent tablets in different formulations

Treatment	**Hardness (N)**	**Friability (%)**	**Water Content (%)**	**Effervescence Time (sec)**	**Solubility (Likert scale)**
Formulation 1	41.44^{d}	0.18^{c}	0.017	114.25^{c}	5.00
Formulation 2	64.07^{a}	0.41^{a}	0.055	216.50^{a}	3.00
Formulation 3	45.21^{c}	0.22^{bc}	0.025	144.25^{b}	5.00
Formulation 4	51.55^{b}	0.30^{b}	0.037	207.25^{a}	4.00
Mean	50.566	0.280	0.034	170.563	4.25
CV	3.284	22.646	62.562	7.034	NA
SE(m)	0.830	0.032	0.011	5.999	NA
CD at 5% level	2.558	0.098	NS	18.484	NA
CD at 1% level	3.587	0.137	NS	25.913	NA

NA = Not Applicable

within 3 min (Sharma, 2013). These findings can also be attributed to a decrease in the particle size, which results in an expanded surface area and facilitates a more efficient and rapid interaction between the acid and base upon contact with water (Khan *et al*., 2014). The noted alterations could be due to the breakdown of bicarbonate while in storage, initiating hydrolysis reactions that, in effect, delay the time it takes for effervescence to occur (Pagire *et al*., 2020).

Solubility

The data on the solubility of the formulated effervescent tablets is given in Table 8. The Likert scale evaluation indicated that the solubility level was high in formulations F1 and F3, whereas F2 presented the lowest solubility. Elevated pH levels in the micro-environment resulted in increased solubility of fumaric acid within the system, consequently generating stronger driving forces for diffusion (Streubel *et al*., 2000).

The prepared effervescent tablets composed of *Salicornea herbacea* salt contain a higher level of phenolic antioxidants and these are even more potent than that of synthetic antioxidants and bamboo silica in effervescent tablets as a promising natural functional ingredient as nutraceutical element with potential bone regeneration properties, anti-aging, anti-osteoporosis, neuroprotective, and hypoglycemic effect (Rondanelli et al., 2021) along with multiple benefits with the inclusion of edible organic acids v.z., fumaric acid for cellular ATP production (Freitag, 2009), adipic acid protects against obesity and diabetes (Xu *et al*., 2019) olive salt is helpful in different health problems like diabetes, digestion, gastric related issues, kidney related issues and also a good source of Vit. E, Fe, Cu and Ca, which in turn project synergistic effects on human health.

Conclusion

The study successfully developed effervescent tablets using a two-step wet granulation method with olive salt and bamboo silica, enhancing drug dissolution and bioavailability. The process was simple, cost-effective, and free of production issues like sticking or capping. All tablets met pharmacopoeial standards, exhibiting desirable mechanical and physical properties. Formulations 1 and 3 were optimal, showing excellent flow properties, smaller particle diameters, and lower densities. Post-compression, these formulations demonstrated superior characteristics, including lower hardness, friability below 0.5%, minimal water content, effervescence time less than 2.5 minutes, and high solubility, making them ideal fast-dissolving effervescent tablets. Effer-

vescent tablets, unique salts, edible alkalizing agents, and organic acids have unique therapeutic properties by supplementing neglected trace elements like silicon, essential for bone health; polyphenols from fruit-based ingredients protect against various diseases.

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Conflict of interest

The authors declare that they have no conflict of interest.

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