



Sustainable growth enhancement of one-year-old Satsuma mandarins saplings using dry yeast suspension and kinetin

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Abstract

Exogenous application of dry yeast suspension and kinetin is considered one of the sustainable strategies for enhancing vegetative growth, however, the potential synergistic effects of combining these two specific inputs on citrus saplings remain poorly understood. To address this, a study was conducted to evaluate the hypothesis that the co-application of dry yeast and kinetin could optimally enhance the growth and biochemical profile of young Satsuma mandarin (*Citrus unshiu* Marc.). The present study was carried out in the lathhouse in College of Agriculture, University of Anbar, Iraq, under subtropical, arid climatic conditions, by using foliar feeding of dry yeast suspension and kinetin. Experimental treatments consisted of two factors: the first one, foliar application of dry yeast suspension with four concentrations, viz., (0, 3, 6 and 9 g L⁻¹); while the second factor included foliar application with kinetin at (0, 50 and 100 mg L⁻¹). A total sample size of 108 sapling were evaluated utilising a randomised complete block design (RCBD). The collected data were statistically analysed using analysis of variance (ANOVA) via GenStat software to determine significant differences. The findings showed that most growth characteristics and biochemical features significantly increased in a dose dependent manner. Significant increases were observed in traits such as the net increase in the length of main shoots, dry vegetative mass and root development parameters like taproot length, number and length of adventitious roots, root dry mass. Furthermore, chlorophyll and biochemical contents of shoots were enhanced. Among the evaluated treatments, dry yeast suspension at concentration 9 g L⁻¹ and kinetin at concentration 100 mg L⁻¹, achieved the highest efficacy compared to other concentration and the control. Practically, these findings offer a sustainable and efficient approach to enhance vegetative growth and biochemical content of saplings in arid and semi-arid regions.

Keywords: citrus saplings; dry yeast suspension; kinetin; Satsuma mandarin; subtropical climate; sustainable agriculture

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1. Introduction

Satsuma mandarin (*Citrus unshiu* Marc.) belongs to the Rutaceae family; they are a common, seedless citrus fruit known for its flavour and easy peeling. It is considered an evergreen fruit tree, cold-tolerant, resistant to high temperature and suitable for sustainable agriculture on account of high yield and tolerance to different conditions. According to recent statistics, Iraq's total citrus production stands at approximately 139744 metric tonnes, reflecting efforts to revive the sector despite prolonged droughts (1–3). Cultivation of the fruit spread in Japan nearly a thousand years ago in Satsuma Prefecture; it was later introduced to the USA, where it is grown in Florida and California. It is native to East Asia and are likely a hybrid of the mandarin and pumelo (4–6). To date, no published studies have investigated the combined application of dry yeast and kinetin on Satsuma mandarin saplings, leaving a critical knowledge gap regarding their potential synergistic effects.

Recent studies have investigated active dry yeast (bread yeast) (*Saccharomyces cerevisiae*) as a promising solution in sustainable agriculture, given its effective role as a natural and environmentally safe growth stimulant and its high ability to improve vegetative growth and productivity. The nutritional value of yeast lies in its richness in amino acids, micro and macro nutrients, B vitamins and cytokinin (7–9). Due to its high content of cytokinin, dry yeast stimulates cell division, which is reflected in the building of macromolecules and chlorophyll synthesis (10, 11). In addition, it supplies the plant with nutrients directly, especially when added by foliar feeding which ensures continuous supply of these elements to the plant and avoids problems of fixation and deposition in the soil (7, 9, 12). Several studies carried out on plant varieties have reviewed the use of active dry yeast suspension and its positive effects on improving vegetative growth and productivity of different crops. For example, a previous study evaluated the effects of activated dry yeast on the behavior of *Minneola*

tangelo trees (13), while another study showed the effect of spraying dry yeast suspension on the chemical content of lemon seedlings (14).

Ongoing studies focus on enhancing plant morphogenesis and biomass accumulation through the use of plant growth regulators (15). In this context, kinetin stands out as a key growth regulator (16). Although initially extracted and purified from non-plant sources, it can also occur naturally within plants as a result of DNA modifications (17). Kinetin belongs to the adenine group within the cytokinin family and plays a pivotal and comprehensive role in guiding physiological processes, it promotes cell proliferation, bud's outgrowth and strengthens the efficiency of the apical meristem (18). Furthermore, it contributes to the movement of nutrients and minerals to treated tissues, stimulates chlorophyll biosynthesis and chloroplast development and plays a role in delaying leaf senescence and hormonally regulating plant appearance (19). Numerous studies have been conducted in this field; for instance, a previous study investigated the synergistic impact of foliar spray with growth regulators on the development of cleopatra mandarin seedlings (20) and another study reported that spraying with kinetin enhances development of olive seedlings Cv. "Sourani" (21). The primary goal of this research was to explore the feasibility of enhancing vegetative growth, root development and chemical composition to accelerate the building of a strong sapling structure via foliar feeding with dry yeast suspension and kinetin, as well as to determine the optimal levels of these substances.

2. Materials and Methods

Experimental site and plant material

The current study was carried out in the lath house of the Department of Horticulture and Landscape Gardening at the College of Agriculture, University of Anbar (geographical location: 33° 25' N, 43° 18' E), which is characterised by a subtropical, arid to semi-arid climatic condition, from April to December 2025, with the aim of demonstrating the possibility of improving some growth features and chemical content of Satsuma mandarin saplings by using foliar feeding of dry yeast suspension and kinetin. On March 20, 2025, the climatic data, including monthly mean maximum and minimum temperatures and humidity were recorded throughout the experimental period (April to November 2025) and are presented in Table 1. The saplings were brought from a private nursery located in the Al-Krayat area, North of Baghdad. One-year old saplings grafted on sour orange (*Citrus aurantium* L.) rootstock were selected with maximum uniformity. Prior to the treatments, the saplings were acclimatised in the lath house for two weeks. This specific cultivar was chosen due to its high economic value, exceptional cold hardiness among citrus species and its widespread cultivation

potential in subtropical regions like Iraq. Botanically, the chosen cultivar is characterised by a compact, slightly spreading and thornless growth habit with distinct dark green, lanceolate leaves. It is renowned for producing high-quality, seedless and easy-to-peel fruits with a balanced sweet-to-acidic flavor profile. A total of 108 uniform Satsuma mandarin saplings were selected, initially the saplings were cultivated in pots (18 × 16 cm) and they were subsequently transplanted into larger pots (33 × 24 cm) filled with (3 : 1) (v/v) mixture of soil and peat moss.

Agricultural practices and pest management

Comprehensive saplings management was carried out as needed, including manual weeding of the pots. To protect saplings from insect and mite pests, plants were sprayed with chemical pesticides at the first signs of infestation. Abamectin 1.8 % at 1 cm³ L⁻¹ and alphacypermethrin 10 % at 1 cm³ L⁻¹ were used on April 6, 2025, to control citrus leafminer, aphids and cutworms. The periodic control program was maintained biweekly throughout May and June, after which spraying operations were suspended during July and August, to be resumed again during September and October. Saplings were fertilised with balanced fertiliser (20 : 20 : 20). Soil mix samples were collected for physical and chemical analysis (Table 2).

Treatments and experimental design

The study included two experimental factors; the first factor included foliar spray with a dry yeast suspension at four concentrations, viz., (0, 3, 6 and 9 g L⁻¹) and they were coded with the symbols Y₀, Y₁, Y₂ and Y₃ respectively and its components are detailed in Table 3 (22). A suspension was prepared by dissolving active dry yeast in warm water in accordance with the doses determined in this study, accompanied by sugar in a 1 : 1 (w/w) ratio and the mix was kept warm overnight (24 hr) to ensure yeast cell activation and stimulate their proliferation (23). The other factor involved kinetin (99 %) at three concentrations, viz., 0, 50 and 100 mg L⁻¹ respectively designated by the symbols K₀, K₁ and K₂ respectively. Kinetin solution was prepared by first dissolving it in 25 mL of 95 % ethanol, then diluting the volume with distilled water to reach 1 L. Spraying was done in early morning during the second week of April, May and June and spray operations was suspended during July and August and resumed during the second week of September, using a 10 L sprayer with the addition of 0.1 % Tween 20 as surfactant.

The following indicators were measured:

Net increase in main shoots (shoots per sapling)

The increment of main shoots was calculated by subtracting the number of shoots recorded before the beginning of the experiment (April 2025) from the final number of shoots observed at the end of the experiment (December 2025).

Table 1. Monthly mean maximum, minimum temperatures and humidity during the experimental period (April to November 2025)

Month	Maximum	Minimum	Humidity (%)	
			Maximum	Minimum
April	31.16	16.26	79.07	23.16
May	37.61	21.35	61.26	14.52
June	42.73	25.36	44.66	9.94
July	43.8	27.20	47.05	9.94
August	44.43	26.50	53.31	10.39
September	42.25	24.23	43.91	10.01
October	36.23	21.33	61.75	20.34
November	25.53	11.41	68.23	23.44

Table 2. Soil analysis (physical and chemical properties) at depth 15 cm

pH	EC (1:1) ds.m ⁻¹	CEC cmolc kg ⁻¹	OM g kg ⁻¹ soil	Sand g kg ⁻¹ soil	Loam g kg ⁻¹ soil	Clay g kg ⁻¹ soil	N mg kg ⁻¹	P mg kg ⁻¹	K mg kg ⁻¹	CaCO ₃ g kg ⁻¹
7.1	2.36	26.33	12.0	723	60	217	59.66	13.8	216.8	176.3

EC: electrical conductivity; CEC: cation exchange capacity; OM: Organic matter; N: nitrogen; P: phosphorus; K: potassium; CaCO₃: calcium carbonate.

Table 3. Chemical analysis of yeast extract used, according to Vi-cor® company, South Caroline Ave, Mason City, USA.

Amino acids (%)		Vitamins (mg 100 g ⁻¹ dry weight)		Minerals	
Alanine	1.69	Vitamin B1	23.33	Nitrogen	6.88 %
Arginine	1.49	Vitamin B2	21.04	Phosphorus	0.66 %
Aspartic Acid	2.32	Vitamin B6	20.67	Potassium	0.95
Cystine	0.63	Vitamin B12	19.17	Magnesium	0.19
Glutamic Acid	3.76	Thiamine	23.21	Calcium	0.17
Glycine	1.45	Riboflavin	27.29	Sulfur	0.48
Histidine	0.71	Insitol	20.43	Iron	107 ppm
Isoleucine	0.85	Biotin	20.04	Zinc	77 ppm
Leucine	1.91	Nicotinic acid	73.92	Copper	5 ppm
Lysine	1.13	Pantothenic acid	38.43	Manganese	13 ppm
Phenylalanine	1.18	P amino benzoic acid	29.49		
Proline	1.29	Folic acid	26.22		
Serine	1.98	Pyridoxine	22.09		
Threonine	1.54	Growth Regulators (ppm)			
Tryptophan	0.25	Adenine	31		
Tyrosine	0.99	Betaines	56		
Valine	1.4				
Methionine	0.4				

Length of main shoots (cm)

In December 2025, the lengths of the shoots growing on the main stem of the saplings were measured. Shoot length was determined from the point of attachment to the main stem to the shoot tip using a measuring tape.

Dry vegetative mass (g)

In December 2025, the dry mass of vegetative parts was measured following separation from the roots. The samples were then washed, cleaned and left to air dry before being placed in an oven to dry until constant mass.

Increase in tap root length (cm)

In December 2025, one sapling was removed from each replicate, its root system was cleaned with water and then surface-dried. The rate of increase was calculated by subtracting the initial length from the final length.

Increase in the number of adventitious roots (roots per sapling)

Root system was cleaned with water and the lateral roots were counted. The rate of increase was calculated by subtracting the initial reading from the final reading

Increase in adventitious roots length (cm)

Adventitious roots length was quantified from the point of attachment to the root tip. The difference between the average root length at the beginning and end of the experiment was calculated.

Roots dry mass (g)

Dry mass of roots were determined after washing the roots and removing the soil, then drying them in an oven to dry until constant mass.

Chlorophyll (mg per 100 g fresh weight)

A previously studied method was followed to estimate the chlorophyll content, 0.2 g fresh weight sample of leaves was taken and sliced to facilitate acetone penetration into the leaf tissue (24). These slices were placed in dark-colored containers, 20 mL of 90 % acetone was added and they were left in a dark place until complete chlorophyll extraction was achieved. The chlorophyll content was then estimated using a spectrophotometer at wavelength of 663 and 645 nm. Based on the obtained readings, the following relation was used:

$$\text{Chlorophyll (mg L}^{-1}\text{)} = 20.2 D (645) + 8.02 D (663) \quad (\text{Eqn. 1})$$

Where,

D = optical density (Absorbance)

$$\text{mg /100 g fresh weight} = V. \text{ total chlorophyll (mg L}^{-1}\text{)} / W.10 \quad (\text{Eqn. 2})$$

where,

V = final volume of extract (mL) and W = the fresh weight of tissue.

Shoot carbohydrate (%), shoot nitrogen (%) and carbon to nitrogen (C/N) ratio

Total carbohydrate content in the branches of saplings was estimated at the end of the experiment in December 2025, according to a previously described method (25). Shoot nitrogen (N) assessment in main branches at the end of the experiment in December 2025 was done according to a previously studied method (26). Carbon to nitrogen (C/N) ratio was calculated by dividing percentage of total carbohydrate to percentage of N.

The experiment was laid out in a randomised complete block design (RCBD) with three replications, using 3 saplings per experimental unit. Data were subjected to analysis of variance (two-way ANOVA) using the GenStat statistical, using least significant differences (LSD) at probability ($p \leq 0.05$) (27).

3. Results and Discussion

Net increase in main shoots (shoot per sapling)

The results presented in Table 4 indicate a significant increase for all concentrations of dry yeast and kinetin and their interaction in increasing shoots number; Y_3 (9 g L^{-1}) and K_2 (100 mg L^{-1}) recorded the maximum averages of 5.66 and 4.77 shoots per sapling respectively, compared to Y_0 and K_0 , which gave 2.92 and 3.66 shoots per sapling respectively. Similarly, the interaction treatment Y_3K_2 was distinguished by the highest average of all at 6.33 shoots per sapling, compared to the control.

Length of main shoots (cm)

The outputs in Table 4 demonstrated a significant effect of dry yeast, kinetin and their interaction on increasing main shoot length. Y_3 and K_2 achieved the highest average length (19.93 and 19.55 cm respectively), compared to Y_0 and K_0 , which gave 13.68 and 15.26 cm respectively. In the same context, the interaction treatment Y_2K_2 gave the maximum value, reaching 23.11 cm, compared to the control.

Dry vegetative mass

The results in Table 4 showed a significant increase in the dry vegetative mass due to treatment with dry yeast and kinetin. Y_3 and K_2 resulted in weights of 68.16 and 68.93 g respectively. Further confirming this superiority, Y_3K_2 achieved the highest dry mass of 76.00 g, compared to 40.93 g for the control treatment.

Table 4. Effect of foliar application with dry yeast suspension, kinetin and their interaction on shoot growth and vegetative dry biomass

Kinetin (K)	Dry yeast (Y)				Mean
	Y ₀ = control	Y ₁ = 3 g L ⁻¹	Y ₂ = 6 g L ⁻¹	Y ₃ = 9 g L ⁻¹	
Net increase in main shoots (shoot sapling ⁻¹)					
K ₀ = control	2.11	3.55	4.11	4.88	3.66
K ₁ = 50 mg L ⁻¹	3.11	4.33	4.55	5.77	4.44
K ₂ = 100 mg L ⁻¹	3.55	4.11	5.11	6.33	4.77
Mean	2.92	3.99	4.59	5.66	
LSD (0.05)	Y	K	Y × K		
	0.25	0.22	0.44		
Length of main shoots (cm)					
K ₀ = control	12.35	13.52	18.33	16.83	15.26
K ₁ = 50 mg L ⁻¹	14.13	16.17	18.33	19.37	17.00
K ₂ = 100 mg L ⁻¹	14.55	19.07	23.11	21.47	19.55
Mean	13.68	16.25	19.93	19.22	
LSD (0.05)	Y	K	Y × K		
	0.61	0.53	1.06		
Dry vegetative mass (g)					
K ₀ = control	40.93	53.77	55.47	55.30	51.37
K ₁ = 50 mg L ⁻¹	48.00	57.27	62.13	73.17	60.14
K ₂ = 100 mg L ⁻¹	54.57	71.00	74.13	76.00	68.93
Mean	47.83	60.68	63.91	68.16	
LSD (0.05)	Y	K	Y × K		
	1.25	1.09	2.17		

LSD ($p \leq 0.05$): least significant difference.

Increase in taproot length (cm)

Data in Table 5 revealed that the application of dry yeast suspension and kinetin significantly affected taproot length. Y₃ and K₂ achieved the highest length (19.63 and 18.67 cm respectively) compared to Y₀ and K₀, which gave 11.44 and 14.61 cm respectively. On the other hand, the interaction between treatments showed a remarkable effect; Y₃K₂ gave the highest length (21.60 cm), in comparison to control (10.55 cm).

Increase in adventitious roots number (root per sapling)

As shown in Table 5, foliar application of dry yeast suspension and kinetin at concentrations Y₃ and K₂ significantly increased the adventitious root number (10.56 and 10.00 roots per sapling), whereas the lowest number was noticed at Y₀ and K₀ (7.22 and 7.25 roots per sapling respectively). In the same context, the interaction treatment, Y₃K₂, showed a noticeable effect, reaching 11.67 roots per sapling, compared to the control.

Increase in adventitious root length (cm)

Data in Table 5 illustrates that the adventitious root length was significantly enhanced by both treatments, especially Y₃ and K₂, which recorded the highest length (15.22 and 15.00 cm), compared to Y₀ and K₀ which gave the minimum value. The interaction between treatments demonstrated a strong synergistic effect; Y₁K₂ achieved the maximum length, reaching 17.33 cm, compared to the control.

Root dry mass (g)

Data in Table 5 indicated that spraying Satsuma mandarin saplings with activated dry yeast and kinetin resulted in a significant increase in root dry mass. The Y₃ and K₂ treatments were the most effective, achieving 32.68 and 31.67 g respectively. Similarly, the dual interaction produced a highly significant response with the Y₃K₂ interaction achieving the highest dry mass of 35.27 g compared to the control.

Table 5. Effect of foliar application with dry yeast suspension, kinetin and their interaction on root growth and root system dry mass

Kinetin (K)	Dry yeast (Y)				Mean
	Y ₀ = control	Y ₁ = 3 g L ⁻¹	Y ₂ = 6 g L ⁻¹	Y ₃ = 9 g L ⁻¹	
Tap root length (cm) increment					
K ₀ = control	10.55	14.66	15.45	17.78	14.61
K ₁ = 50 mg L ⁻¹	10.93	16.06	15.81	19.51	15.58
K ₂ = 100 mg L ⁻¹	12.84	19.39	20.87	21.60	18.67
Mean	11.44	16.70	17.38	19.63	
LSD (0.05)	Y	K	Y × K		
	0.50	0.43	0.86		
Adventitious roots number (root sapling ⁻¹) increment					
K ₀ = control	5.67	6.67	7.00	9.67	7.25
K ₁ = 50 mg L ⁻¹	6.67	9.00	9.67	10.33	8.92
K ₂ = 100 mg L ⁻¹	9.33	8.67	10.33	11.67	10.00
Mean	7.22	8.11	9.00	10.56	
LSD (0.05)	Y	K	Y × K		
	0.74	0.42	0.98		
Adventitious roots length (cm) increment					
K ₀ = control	7.34	9.67	12.33	13.00	10.59
K ₁ = 50 mg L ⁻¹	10.33	12.00	12.87	17.00	13.05
K ₂ = 100 mg L ⁻¹	13.17	17.33	13.83	15.67	15.00
Mean	10.28	13.00	13.01	15.22	
LSD (0.05)	Y	K	Y × K		
	0.85	0.74	1.48		
Root dry mass (g)					
K ₀ = control	19.34	22.98	29.23	29.53	25.27
K ₁ = 50 mg L ⁻¹	26.30	28.53	32.43	33.23	30.12
K ₂ = 100 mg L ⁻¹	27.63	31.10	32.67	35.27	31.67
Mean	24.43	27.54	31.44	32.68	
LSD (0.05)	Y	K	Y × K		
	1.03	0.89	1.78		

LSD (P ≤ 0.05): least significant difference.

Chlorophyll (mg per 100 g fresh weight)

According to the data illustrated in Table 6, spraying with activated dry yeast and kinetin and their combination significantly increased chlorophyll content. Treatment Y₃ and K₂ achieved the highest content (232.14 and 226.28 mg per 100 g fresh

weight respectively), with an increase of (11.88 and 6.46 % respectively), compared to Y₀ and K₀. Likewise, the interaction between treatments showed a significant effect; the Y₃K₂ recorded the highest value at 245.78 mg per 100 g fresh weight compared to the control.

Table 6. Effect of foliar application with dry yeast suspension, kinetin and their interaction on chemical content and C/N ratio

Kinetin (K)	Dry yeast (Y)				Mean
	Y ₀ = control	Y ₁ = 3 g L ⁻¹	Y ₂ = 6 g L ⁻¹	Y ₃ = 9 g L ⁻¹	
Chlorophyll (mg per 100 g fresh weight)					
K ₀ = control	204.44	209.46	211.47	224.80	212.54
K ₁ = 50 mg L ⁻¹	207.42	211.43	216.10	225.83	215.20
K ₂ = 100 mg L ⁻¹	210.60	229.03	219.69	245.78	226.28
Mean	207.49	216.64	215.75	232.14	
LSD (0.05)	Y	K	Y × K		
	2.40	2.08	4.16		
Shoot carbohydrate (%)					
K ₀ = control	7.03	7.56	8.35	10.45	8.35
K ₁ = 50 mg L ⁻¹	7.80	8.45	9.03	10.80	9.02
K ₂ = 100 mg L ⁻¹	9.91	10.62	11.18	11.88	10.90
Mean	8.25	8.87	9.52	11.04	
LSD (0.05)	Y	K	Y × K		
	0.25	0.22	0.44		
Shoot nitrogen (%)					
K ₀ = control	0.459	0.549	0.595	0.585	0.547
K ₁ = 50 mg L ⁻¹	0.532	0.522	0.613	0.624	0.573
K ₂ = 100 mg L ⁻¹	0.541	0.573	0.544	0.654	0.578
Mean	0.511	0.548	0.584	0.621	
LSD (0.05)	Y	K	Y × K		
	0.017	0.015	0.030		
C / N Ratio					
K ₀ = control	15.32	13.75	14.04	17.87	15.25
K ₁ = 50 mg L ⁻¹	14.65	16.22	14.71	17.31	15.72
K ₂ = 100 mg L ⁻¹	18.31	18.54	20.54	18.21	18.90
Mean	16.09	16.17	16.43	17.80	
	Y	K	Y × K		
	0.69	0.59	1.19		

LSD ($P \leq 0.05$): least significant difference.

Shoot carbohydrate (%)

Statistical analysis shown in Table 6 indicates that spraying saplings with activated dry yeast and kinetin resulted in a superior and proportional increase in saccharide content. Treatments Y₃, K₂ and their interaction Y₃K₂ achieved the highest value, reaching 11.04, 10.90 and 11.88 % for each treatment respectively, compared to the Y₀, K₀ and the control treatment.

Shoot nitrogen (%)

Statistical analysis shown in Table 6 indicates that spraying Satsuma mandarin saplings with dry yeast suspension, kinetin and their combined application

significantly increased the N content. Treatments Y₃, K₂ and their interaction showed a significantly higher increase of 0.621, 0.578 and 0.654 %, while Y₀, K₀ and the control treatment gave the lowest percentage of N content.

Carbon to nitrogen (C/N) ratio

According to the data in Table 6, feeding with activated dry yeast and kinetin and the interaction between them resulted in a significant increase in the C/N ratio. Treatments Y₃ and K₂ and their interaction achieved the highest values, reaching 17.80, 18.90 and 20.54 for each treatment respectively, compared to Y₀, K₀ and the control treatment, which gave 16.90, 15.25 and 13.75 respectively.



Concurrently, the co-application of dry yeast suspension in enhancing growth parameters may be attributed to the critical components of dry yeast suspension (Table 3) due to its amino acid content. The amino acid content influences the synthesis of secondary compounds, activates the plant's enzyme system, particularly the oxidation–reduction system, increases cell division and elongation and enhances the efficiency of C metabolism and the synthesis of carbohydrates and proteins, thus contributing to increased vegetative growth (28, 29). Alternatively, it may be attributed to its significant role in stimulating physiological and biochemical processes. Amino acids as the building blocks of proteins, stimulate photosynthesis and carbohydrate synthesis and contribute to the formation and activation of several enzymes and coenzymes, ultimately leading to improved plant growth (30). Furthermore, they act as a bio stimulant, positively impacting plant growth and effectively mitigating the effects of environmental stresses (31). Nutrients, including N, potassium (K) and phosphorus (P), also play an essential role in the biochemical pathway. Photosynthesis is influenced by N, as it is involved in the composition of cytochromes necessary for photosynthesis and respiration (32). The synergistic interaction ensures that the cellular building blocks and co-factors supplied by the yeast are efficiently utilised in the rapidly dividing meristematic tissues stimulated by kinetin, as evidenced by the superior performance of the Y_3K_2 .

Roots are a fundamental pillar in plant life, playing a pivotal role in absorbing nutrients and providing the necessary structural support (33, 34). The results in Table 5 demonstrate a significant positive effect of treating saplings with a dry yeast suspension and the growth regulator kinetin on root growth indicators, which included the rate of increase in taproot length, the rate of increase in the number of adventitious roots, the rate of increase in adventitious root length and the dry root mass. This may be attributed to the ability of these substances to stimulate the overall performance of the vegetative system, which necessarily leads to enhancing root characteristics as a direct result. According to a previous study activating the vegetative system leads to an increase in the efficiency of photosynthesis and thus the transfer of excess carbohydrates and other manufactured materials from the leaves to the roots, which supports their growth and spread, thus increasing dry matter (35). The maximum adventitious root length observed at Y_1K_2 (17.33 cm) compared to Y_3K_2 (15.67 cm) can be attributed to the supra-optimal concentration effect. Root elongation is highly sensitive to hormone and nutrient balances. While higher yeast levels (Y_3) enhanced shoot proliferation, they likely resulted in a supra-optimal accumulation of auxins or nutrients in the root zone, triggering a slight feedback inhibition on root elongation. Conversely, the lower yeast level (Y_1) maintained an optimal hormonal balance that favoured longitudinal root cell division and elongation. These results are consistent

with what many scientific studies in this field have concluded, most notably (36, 37) which explored the impact of activated yeast on one-year-old sour orange seedlings. Similar findings were reported which studied the effect of spraying a dry yeast suspension on certain growth characteristics of citrus rootstock seedlings (23). Another study investigated the effect of spraying with kinetin on the growth of Cleopatra mandarin citrus rootstock seedlings (38). Similar findings were reported which studied the effect of kinetin application on certain growth characteristics of olive seedlings (21, 39).

The increase in branch carbohydrate content resulting from spraying with the dry yeast suspension and the growth regulator kinetin may be attributed to the positive role of both compounds in protecting chlorophyll pigment and reducing its degradation, leading to an increase in its content in the leaves. Since chlorophyll is the primary pigment in photosynthesis and sugar synthesis, this increase coincided with an expansion of leaf area, which positively impacted root growth. This overall development resulted in enhanced nutrient absorption and increased nutrient concentration in the leaves, leading to an improvement in the overall nutritional status of the saplings and facilitating the translocation of carbohydrates and synthesised substances from the leaves to other parts, particularly branches and stems.

4. Conclusion

Understanding the pivotal role of dry yeast suspension and growth regulators like kinetin is crucial because yeast extract contains free amino acids and proteins, as well as vitamins (B group vitamins), nucleic acids, lipids and minerals such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe) and zinc (Zn). Foliar spray thus allows for rapid absorption, bypassing soil limitations in arid or nutrient-poor conditions. This study was carried out to explore the potential of enhancing Satsuma mandarin sapling growth via foliar application with dry yeast suspension and kinetin. Based on the evidence, it can be inferred that the combined application of activated dry yeast (9 g L^{-1}) and kinetin (100 mg L^{-1}) and the interaction yielded the optimum results for growth characteristics, including the number and length of adventitious shoots, dry mass, primary root length, number and length of adventitious root, dry root mass, chlorophyll content, carbohydrate, N and carbon to nitrogen (C/N) ratio.

Practical utilisation, extent and future scope

The findings of this study can be directly utilised in commercial citrus nurseries and sustainable agricultural systems across arid and semi-arid zones. To a large extent, this eco-friendly protocol (combining dry yeast and kinetin) serves as a cost-effective alternative to synthetic chemical

fertilisers, enabling growers to accelerate the nursery production cycle and produce robust, stress-tolerant Satsuma mandarin saplings in a shorter timeframe.

Future scope

Subsequent research should extend to field trials to evaluate the long-term impact of these nursery treatments on fruit yield and quality after transplanting. Additionally, molecular and enzymatic analyses are highly recommended to unveil the exact internal pathways regulated by the yeast-kinetin synergistic interaction under changing climatic conditions.

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Authors' contributions

THRAF generated the idea of this research and write the literature survey to actualise the concept for this research, performed the statistical analysis to evaluate the individual and interactive effects of the factors and critically reviewed the final manuscript. AHI conducted the experiments, collected the data, interpreted the results, prepared the original draft manuscript, compared the findings with the existing literature and formulated the final conclusions. Both authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

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