

1 **Optimizing garlic (*Allium sativum*) yield through**
2 **irrigation scheduling and nitrogen management**

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8 **ABSTRACT**

Aims: Efficient utilization of natural resources, such as water and nutrients, plays a pivotal role in enhancing crop yield and overall productivity.

Study design:

Place and Duration of Study: To delve into the intricate interaction between water and nitrogen use efficiency in garlic cultivation, a two-year-long experiment was conducted.

Methodology: The experiment consisted of twelve treatment combinations, encompassing four distinct irrigation schedules (I0 as the control, I1 with 4 cm irrigation at an IW/CPE ratio of 0.8, I2 at 1.0, and I3 at 1.2) and three nitrogen levels (N0 as the control, N1 at 75%, and N2 at 100% of the recommended nitrogen dose).

Results: These treatments were replicated thrice using a factorial randomized block design. Notably, the irrigation schedule I3 exhibited a significant increase in nitrogen use efficiency, consequently resulting in higher garlic yields compared to the control irrigation (I0). Given the substantial difference in bulb yield observed in the I3 level (136.0 q/ha) compared to the control, it can be considered an efficient irrigation schedule for garlic cultivation. Among the tested nitrogen levels, N2 emerged as the most favorable, yielding significantly higher garlic production. The treatment combination of I3N2 recorded the highest bulb yield, boasting a remarkable increase of 64.5% over the control.

Conclusion: In summary, this study underscores the effectiveness of the I3N2 treatment combination for achieving robust growth and increased garlic yields while optimizing the utilization of irrigation water and nitrogen resources.

9
10 *Keywords: Garlic, water use efficiency, nitrogen use efficiency, irrigation, yield*

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12 **1. INTRODUCTION**

13
14 The most important bulb crop garlic (*Allium sativum*) belongs to the family Alliaceae contains proteins,
15 lipids, carbohydrates, fibre, alkaloids and vitamins uses as a food preservative. Garlic production in the
16 country has shown steady increase in last few years and it is the second most important bulb crop in
17 India. The global scenario of area and production of garlic shows that it is grown in an area of 12 million
18 hectares with a production of 16.4 million tons globally (FAO, 2008). Although, the productivity of garlic in
19 Himachal Pradesh is almost three times higher than that of national average, but it is still lower than its
20 potential yield. There is a lot of scope to enhance its productivity by lowering down the gap between
21 potential yield and actual yield (Zala *et al.* 2014). In many garlic producing areas, lack of available
22 nutrients and availability of soil water are two main limiting factors for the low productivity of garlic.
23 Therefore, through proper irrigation and nutrient management practices we can enhance its productivity
24 and bring it near to its potential yield.

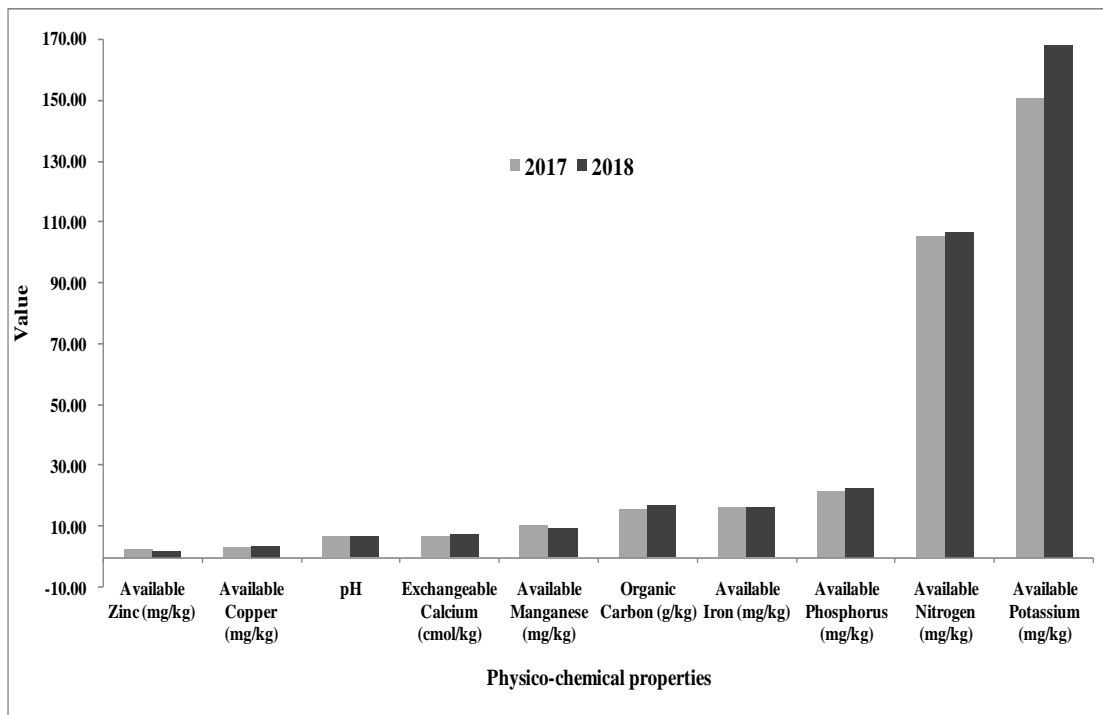
25 The frequency of irrigation and the amount of water required are governed by various factors such as
26 cultivar, soil types, season, distribution of rainfall and management practices etc (Singh *et al.* 2008).

27 Irrigation scheduling is a water management strategy which prevent over application of water while
 28 minimizing the yield loss due to water shortage or drought stress. Both over irrigation as well as under
 29 irrigation adversely affect the garlic yield. The importance of irrigation scheduling is that it enables the
 30 irrigator to apply exact amount of water to achieve the goal of increased irrigation efficiency (Imitiyaz *et*
 31 *al.*, 2000). On the other hand, judicious application of fertilizers is important for garlic production. Nitrogen
 32 fertilization is necessary for ensuring successful vegetative growth. However, it is most often the limiting
 33 nutrient element in plant growth and is a constituent of chlorophyll, plant proteins and nucleic acids. The
 34 efficient use of N from the economic point of view can be achieved by soil moisture management through
 35 efficient irrigation schedule. Keeping in view, a study carried out to develop an efficient irrigation schedule
 36 and nitrogen and irrigation interaction effect to achieve higher productivity along with water use efficiency
 37 in garlic.

38 2. MATERIAL AND METHODS

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40 To achieve objectives of present study field experiments were conducted for two consecutive winter
 41 seasons 2017-2018 in the experimental farm, Dr. Yashwant Singh Parmar University of Horticulture and
 42 Forestry, Nauni, Solan, Himachal Pradesh.



43

44 **Figure 1. Physico-chemical properties of the experimental soil (depth 0-15 cm)**

45 2.1 Soil analysis

46 Prior to conducting the experiment, representative soil samples were collected from a depth of 0-15 cm.

47 These samples were gathered to investigate the impact of varying irrigation and nitrogen levels on several

48 soil parameters, including pH, soil organic carbon, available nitrogen, phosphorus, potassium, exchangeable
 49 calcium, and the availability of micronutrient cations such as iron, manganese, zinc, and copper (Figure 1).

50 **2.2 Experimental details and data analysis**

51 A total of 12 treatment combinations, comprising different irrigation schedules (I0: 0.0 IW/CPE, I1: 0.8
 52 IW/CPE, I2: 1.0 IW/CPE, I3: 1.2 IW/CPE) and nitrogen levels (N0: 0.0% N fertilizer, N1: 75% of N
 53 fertilizer, N2: 100% of N fertilizer), were arranged in a Factorial Randomized Block Design with three
 54 replications. The experimental field underwent thorough plowing using a tractor, followed by planking, 15
 55 days prior to the actual sowing date. A total of thirty-six raised plots, each measuring 3 m × 2 m, were
 56 established. All the agronomic practices necessary for garlic bulb production were carried out according
 57 to recommended guidelines. To assess yield and related traits, including plant height (cm), number of
 58 leaves per plant, number of cloves per bulb, biological yield (q/ha), and bulb yield (q/ha), five plants were
 59 randomly chosen and marked in each treatment. The data recorded was analyzed by using MS-Excel
 60 and OPSTAT software. The mean values of data were subjected to analysis of variance (ANOVA) as
 61 described by Panse and Sukhatme (2000) for using Factorial Randomized Block Design.

62 **3. RESULTS AND DISCUSSION**

63
 64 Prior to conducting the experiment, the soil profile underwent meticulous analysis over two consecutive
 65 seasons at a depth of 0-15 cm. The findings indicated that all the examined physio-chemical properties
 66 exhibited statistically similar results (Figure 1).

67 **Table 1. Effect of irrigation and N levels on plant height (cm), number of leaves per plant and**
 68 **number of cloves per bulb in garlic**

Treatment s	Plant height (cm)			Number of leaves per plant			Number of cloves per bulb		
	2016- 17	2017- 18	Pooled	2016-17	2017-18	Pooled	2016- 17	2017- 18	Pooled
I0N0	39.20	47.20	43.20	7.50	8.50	8.00	10.30	10.50	10.40
I1N0	48.20	56.80	52.50	9.70	10.60	10.20	10.90	10.60	10.80
I2N0	50.00	57.60	53.80	9.70	11.30	10.50	10.90	11.10	11.00
I3N0	50.30	59.90	55.10	9.90	11.40	10.70	11.50	11.90	11.70
I0N1	50.40	53.10	51.70	10.40	10.80	10.60	11.70	11.80	11.70
I1N1	59.00	60.30	59.70	12.70	13.20	12.90	14.30	14.30	14.30
I2N1	61.50	63.70	62.60	12.70	13.30	13.00	14.30	14.50	14.40
I3N1	62.90	65.40	64.20	12.90	13.60	13.20	14.70	15.10	14.90
I0N2	52.70	59.30	56.00	11.00	11.60	11.30	11.90	11.90	11.90
I1N2	61.30	68.50	64.90	13.10	13.80	13.50	14.30	14.60	14.40
I2N2	65.60	70.10	67.90	13.20	13.90	13.60	15.40	15.10	15.20
I3N2	69.60	70.50	70.00	13.40	14.00	13.70	15.70	15.70	15.70
Mean	55.89	61.03	58.47	11.35	12.17	11.77	12.99	13.09	13.03
Critical Difference at 5% level of significance									
I	1.00	0.70	0.70	NS	0.20	NS	0.50	0.30	0.30
N	0.90	0.60	0.60	NS	0.20	NS	0.40	0.30	0.30
IxN	1.80	1.20	1.20	NS	NS	NS	0.80	0.60	0.50

69 **I0: (Control), I1: (0.8 IW/CPE ratio), I2: (1 IW/CPE ratio), I3: (1.2 IW/CPE ratio)**
 70 **N0: Control, N1: 75% of RDN, N2: 100% of RDN**

71 **3.1 Effects of irrigation scheduling and nitrogen levels on garlic production**

72 **3.1.1 Plant height**

73 An acquisition of the data in Table 1 showed statistically significant effect of irrigation levels, N levels and
74 their interaction on plant height across years. However, in I3, plant height (60.9 and 65.3 cm) was
75 significantly higher as compared to control (I0), while, N2 level exhibited significantly higher plant height
76 (62.3 and 67.1 cm) across the years, respectively. Furthermore, interaction of I3 and N2 showed
77 significantly highest plant height (69.6 cm and 70.5 cm) in the respective years. Moreover, pooled
78 analysis of data also showed the comparable results of main and interaction of water and nitrogen for
79 plant height. The results of present study are also in close conformity with the findings of Aregawi (2006)
80 and Farooqui *et al.* (2009) in garlic, who also reported that increased amount of N fertilizer applied,
81 increased the plant height significantly. Kakar *et al.* (2002) and Gebrehaweria (2007) have also reported
82 significant effect of N on plant height in garlic. The increase in height could also be attributed to the
83 involvement of N in building blocks for the synthesis of amino acids, as they link together to form proteins
84 and make up metabolic processes required for plant growth.

85 **3.1.2 Number of leaves per plant**

86 The number of leaves per plant showed insignificant main (irrigation and nitrogen levels) and interaction
87 effects in 2016-17 and pooled data (Table 1). In year 2017-18, main (irrigation and nitrogen levels) had
88 significant effect but interaction had insignificant effect. Main effect I3 and N2 levels had significantly high
89 number of leaves per plant (13.0 and 13.3) as compared to control, respectively. The results obtained are
90 in line with those of Ahmed *et al.* (2007) and Ahmed *et al.* (2009) in garlic and Biswas *et al.* (2010) in
91 onion who also observed that increasing the irrigation frequency caused an increase in number of leaves
92 per plant. The more number of leaves in plant grown under higher N level might have been associated
93 with the application of N in adequate quantity that positively improved the vegetative growth of garlic.

94 **3.1.3 Number of cloves per bulb**

95 The number of cloves per bulb showed significant main effect (irrigation and N levels) and interaction
96 effect across years and pooled data (Table 1). In irrigation level, the highest number of cloves per bulb
97 (13.9, 14.2 and 14.1) was observed in I3 level during 2016-17, 2017-18 and pooled data, respectively.
98 Furthermore, in nitrogen level, N2 level exhibited the highest number of cloves per bulb (14.3 each) in
99 2016-17, 2017-18 and pooled data, respectively. The interaction (I×N) effect was also significant on
100 number of cloves pre bulb in both the years and pooled data. These findings are in close agreement with
101 other workers like Singh *et al.* (2007) and Doro (2012) in garlic. The results of Setty *et al.* (1989) also
102 stated that application of N fertilizers significantly increased bulb size and number of cloves in garlic.

103 **3.1.4 Biological yield (q/ha)**

104 In two consecutive years and pooled data of present study, the effect of irrigation and N levels and
105 interaction effect on biological yield (q/ha) was found to be significant (Table 2). In irrigation level, I3 had

106 significantly high mean biological yield (245.7 and 269.4 q ha⁻¹) whereas in N levels, the N2 level had
 107 significantly high mean biological yield (261.5 and 282.2 q ha⁻¹) as compared to control (N₀ level) during
 108 both the years. In case of interaction effect (I×N) significantly higher biological yield of garlic (295.0 and
 109 310.0 q ha⁻¹) was found in I₃N₂ in 2016-17 and 2017-18, respectively. Furthermore, in pooled data the I₃
 110 had significantly higher biological yield (257.5 q ha⁻¹) while N₂ level had significantly higher (271.9 q ha⁻¹)
 111 biological yield while In case of interaction effect I₃N₂ had significantly higher biological yield (302.5 q ha⁻¹
 112 ¹). Higher biological yield of garlic under N₂ might be due to complete solubility, mobilization and
 113 availability of N at regular interval in required quantity. The reason suggested for such a response was
 114 that optimum N application increased growth parameters, which in turn synthesized more plant
 115 metabolites thereby, increasing crop yield Similar results were also reported by Naruka *et al.* (2005) and
 116 Gowda *et al.* (2007) in garlic.

117 **Table 2. Effect of irrigation and N levels on bulb yield (q/ha) and biological yield (q/ha) in garlic**

Treatments	Bulb yield (q/ha)			Biological yield (q/ha)		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
I0N0	87.30	100.00	93.80	155.20	175.30	165.20
I1N0	98.10	108.00	103.00	170.80	190.70	180.70
I2N0	102.40	117.00	110.00	177.90	202.00	190.00
I3N0	108.70	126.00	117.00	188.90	214.80	201.90
I0N1	101.70	119.90	110.80	171.50	197.10	184.30
I1N1	118.10	136.00	127.10	239.70	264.70	252.20
I2N1	121.10	142.30	131.70	245.30	273.60	259.50
I3N1	124.40	147.70	136.10	253.00	283.40	268.20
I0N2	111.70	129.30	120.50	196.10	222.00	209.10
I1N2	133.30	150.60	141.90	271.20	295.40	283.30
I2N2	142.90	153.80	148.30	283.80	301.50	292.60
I3N2	149.80	158.70	154.30	295.00	310.00	302.50
Mean	116.63	132.44	124.54	220.70	244.21	232.46
Critical Difference at 5% level of significance						
I	2.60	1.30	1.40	2.40	1.20	1.40
N	2.20	1.10	1.20	2.10	1.10	1.20
I×N	4.50	2.20	2.50	4.20	2.10	2.40

118 **I0: (Control), I1: (0.8 IW/CPE ratio), I2: (1 IW/CPE ratio), I3: (1.2 IW/CPE ratio)**

119 **N0: Control, N1: 75% of RDN, N2: 100% of RDN**

120 **3.1.5 Bulb yield (q/ha)**

121 Table 2 showed the significant main effect (irrigation and N levels) on bulb yield during both the years and
 122 pooled data. In irrigation levels, during 2016-17, 2017-18 and pooled data I₃ exhibited significantly
 123 highest bulb yield (127.6, 144.4 and 136.0 q/ha) whereas in nitrogen levels, N₂ level had significantly
 124 highest bulb yield (134.4, 148.1 and 141.3 q/ha) as compared to control, respectively. Furthermore,
 125 interaction I₃N₂ was recorded significant during both the years and pooled data in this study. Higher bulb
 126 weight and bulb yield with irrigation level I₃ might be due to optimum soil moisture regimes (Table
 127 2) throughout the growing period which might have facilitated greater nutrient uptake and proper soil
 128 physical environment to help the plant to put forth better vegetative growth and yield. Better expression
 129 of growth and yield under higher quantity of irrigation and N was also reported by Singh *et al.* (2007)

130 and Doro (2012) in garlic and Dorcas *et al.* (2012) and Kumar *et al.* (2007) in onion. The enhanced
 131 bulb yield under N₂ might be related to sufficient application of N that significantly influenced the plant
 132 performance. Studies of Assefa *et al.* (2015) revealed that better N supply to the plant increased the rate
 133 of metabolism where more synthesis of carbohydrate takes place. This in turn increased the bulb weight
 134 and total yield of garlic. An adequate supply of N is therefore, associated with vigorous vegetative growth
 135 and more efficient use of available inputs finally leading to higher productivity. Improvement in overall
 136 growth i.e. plant height, leaf length and number of leaves with irrigation coupled with increased net
 137 photosynthesis towards reproduction structure, which increased the yield attributes significantly. These
 138 findings are in close agreement with previous studies i.e. Singh *et al.* (2007) and Doro (2012) in garlic
 139 and Dorcas *et al.* (2012) in onion. Additionally, Akbar *et al.* (2023) found a higher bulb yield in responsive
 140 drip irrigation compared to furrow irrigation in silty loam soil. Furthermore, Alemayehu *et al.* (2023)
 141 revealed that the combined effect of irrigation water and NPS fertilizer significantly increased potato tuber
 142 yield.

143 **Table 3. Nitrogen and water use efficiency in garlic cultivation**

Treatments	Nitrogen use efficiency (%)			Water use efficiency (%)		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
I ₀ N ₀	-	-	-	373.7	294.3	334.0
I ₁ N ₁	18.06	24.32	21.19	251.9	261.0	256.4
I ₂ N ₂	31.71	32.58	32.15	247.0	262.5	254.8
I ₃ N ₀	-	-	-	224.8	270.3	247.5
I ₀ N ₁	14.51	18.64	16.58	435.0	351.9	393.5
I ₁ N ₂	28.23	32.10	30.16	303.2	325.8	314.5
I ₂ N ₀	-	-	-	292.1	317.6	304.9
I ₃ N ₁	25.23	29.56	27.39	257.3	315.2	286.3
I ₀ N ₂	19.92	24.31	22.11	477.8	379.3	428.6
I ₁ N ₀	-	-	-	342.1	360.8	351.4
I ₂ N ₁	20.29	25.34	22.82	344.7	343.4	344.0
I ₃ N ₂	35.10	34.49	34.80	309.9	338.7	324.3

144 I₀: (Control), I₁: (0.8 IW/CPE ratio), I₂: (1 IW/CPE ratio), I₃: (1.2 IW/CPE ratio)

145 N₀: Control, N₁: 75% of RDN, N₂: 100% of RDN

146 3.2 Water and nitrogen use efficiency of garlic production

147 3.2.1 Nitrogen use efficiency (NUE) (%)

148 It is evident from Table 3 that during 2016-17, the highest NUE (35.10 %) was observed under I₃N₂
 149 followed by I₂N₂ (31.71 %) and lowest (14.51 %) under I₀N₁ followed by I₁N₁ (18.06 %) while during 2017-
 150 18, the highest NUE (34.49 %) was recorded under I₃N₂ followed by I₂N₂ (32.58 %) and lowest (18.64 %)
 151 under I₀N₁ followed by I₀N₂ (24.31 %). On pooled basis, the highest NUE (34.80 %) was recorded under
 152 I₃N₂ and lowest (16.58 %) under I₀N₁. The results are in accordance with the findings of Liao *et al.* (2009)
 153 in radish and Yadan and Xin (2017) in tomato who also reported that NUE increased with increase in the
 154 amount of water applied. Similar finding was observed by Yadav *et al.* (2010) in onion. Alemayehu *et al.*
 155 (2023) revealed that higher rate of NPS fertilizer application increased nutrient use efficiency.

156 3.2.2 Water use efficiency (WUE)

157 Water use efficiency was calculated on the basis of yield and irrigation water applied during both the

158 years of study. To maximize WUE, it is necessary to conserve water and to promote maximum crop
159 growth. A perusal of data in Table 3 revealed that among irrigation levels, the highest WUE (428.8 and
160 341.8 kg ha⁻¹ cm⁻¹) was recorded under I₀ and the lowest (264.0 and 308.0 kg ha⁻¹ cm⁻¹) under I₃ irrigation
161 level during both the years. Among N levels, highest WUE (575.1 and 434.6 kg ha⁻¹ cm⁻¹) was noticed
162 under N₂ and **the** lowest (205.1 and 241.9 kg ha⁻¹ cm⁻¹) under N₀ during both the years of study. On
163 pooled data, the highest WUE was recorded under I₀ (385.3 kg ha⁻¹ cm⁻¹), which was 34.72 per cent
164 higher over I₃ (286.0 kg ha⁻¹ cm⁻¹) irrigation level. As WUE is the ratio of yield to that of water applied,
165 comparatively lower water applied gave higher WUE. This might be due to inverse relation between WUE
166 and amount of irrigation water applied. WUE decreased with higher irrigation regime. This might be due to
167 fact that the increase in yield was not proportionate to the increase in consumptive use of water. These
168 results corroborated with the findings of Singh *et al.* (2008) and Thenmozhi and Duraisamy (2014) in
169 onion and Zala *et al.* (2014) in garlic. **In agreement with this Lellis *et al.* (2022) found IWUE from 2.53 to**
170 **3.72 kg/m³ with the application of irrigation water. Ayele *et al.* (2023) found that combined effect of**
171 **conventional furrow irrigation with 100% evapotranspiration resulted in the lowest water use efficiency in**
172 **garlic production in Ethiopia.**

173 **4. CONCLUSION**

174

175 The study aimed to investigate the impact of varying irrigation schedules and nitrogen levels on garlic
176 yield, as well as water and nitrogen use efficiency. Among **the** tested nitrogen levels, N₂ (at 100% of the
177 recommended N dose) proved to be the most effective, resulting in **significantly** higher garlic yields.
178 Furthermore, irrigation schedule I₃ demonstrated an increase in nitrogen use efficiency (NUE) and garlic
179 yield when compared to the control irrigation schedule. When combined, irrigation schedule I₃ with N₂
180 substantially enhanced NUE in garlic compared to the control. The significant difference in garlic bulb
181 yield observed under the I₃N₂ treatment combination makes it a compelling choice for achieving both
182 higher garlic yields and improved water and nitrogen use efficiency. Based on the two-year study, it can
183 be concluded that an efficient irrigation schedule and an appropriate nitrogen level are essential factors
184 for maintaining optimal soil moisture conditions and creating a conducive environment for maximizing
185 garlic growth and yield.

186 **ACKNOWLEDGEMENTS**

187 This research was undertaken as part of the first author's Master's degree program at Dr. YS Parmar
188 University of Horticulture and Forestry, Solan, India. The authors express their gratitude to the dedicated
189 technical staff of the Department of Soil Science and Water Management for their invaluable support and
190 provision of essential research facilities.

191

192 **Competing interests**

193 Authors have declared that no competing interests exist.

194 **AUTHORS' CONTRIBUTIONS**

195 Conceptualization of research (KKS); Designing of the experiments (KKS and JCS); Contribution of
196 experimental materials (KKS and JCS); Execution of field/lab experiments and data collection (KKS and
197 JCS); Analysis of data and interpretation (KKS, KCS and SKS); Preparation of the manuscript (KKS, JCS
198 and SKS). All authors read and approved the final manuscript.

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