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Effect of Nitrogen Rate on Growth, Yield, Economics and Crisps Quality of Indian Potato Processing Cultivars

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Abstract A field study was conducted during 2000–2001 and 2001–2002 at the Central Potato Research Institute Campus, Modipuram, India, in order to increasing the processing-grade tuber yield of India's first ever developed processing potato cultivars, Kufri Chipsona-1 and Kufri Chipsona-2. Tuber yield and post-harvest quality characteristics were evaluated in response to five N levels (0, 90, 180, 270 and 360 kg N ha^{-1}). The crop growth traits (stem number, plant height and compound leaf number) responded positively to N application, whereas the effect of N fertilization on processing-grade tuber number, total tuber number per ha and tuber number per plant was quadratic. There was a steady increase in tuber weight per plant, processing-grade tuber yield, total tuber yield and biomass yield in response to N application. Kufri Chipsona-1 produced a 23.6% higher tuber yield per plant than Kufri Chipsona-2. Agronomic N use efficiency decreased linearly with increased N doses. Specific gravity and tuber dry matter percentage responded positively to N application, while crisps colour (at harvest and after storage) and reducing sugars remained unaffected. Cultivar was the major factor that influenced the tuber quality parameters (specific gravity, crisps colour). Higher values of these quality traits were observed in Kufri Chipsona-2 as compared to Kufri Chipsona-1. Net income and benefit cost ratio (B:C) indicated that Chipsona cultivars should be fertilized with 270 kg N ha^{-1} for realizing higher processing-grade yields and desirable quality tubers.

Keywords Crisping · Nitrogen rate · Nitrogen use efficiency · Potato · Processing-grade · Processing quality

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Abbreviations

AE_N agronomic N use efficiency
B:C benefit cost ratio
DAP days after planting
EOD economic optimum dose
FBY fresh biomass yield
FTY fresh tuber yield
HI harvest index
NI net income
Rs. Indian Rupees
TC total costs
TR total return

Introduction

The market for processed potato products, especially crisps and French fries, has been expanding rapidly in India over the last decade. This has led to increased demand for processing-grade potatoes with desirable processing attributes (Pandey and Sarkar 2005). Sensing the market demand, the Central Potato Research Institute developed and released two processing cultivars, Kufri Chipsona-1 and Kufri Chipsona-2, for commercial cultivation in the country in 1998 (Gaur et al. 1998; Gaur et al. 1999). When grown with the recommended fertilizer doses for the region, these two cultivars yielded a low proportion of processing-grade tubers. This necessitated standardization of nutritional requirements with a view to enhancing the proportion of processing-grade tubers in Chipsona cultivars. Among the major nutrients, the role of nitrogen (N) fertilization for tuber growth, development, yield and quality is well documented (Ojala et al. 1990). Inadequate N fertilization leads to poor crop growth and yield, while excessive application leads to delayed maturity, poor tuber quality, excessive nitrate leaching and occasionally reduction in tuber yield (Lauer 1986; Harris 1992). Tuber quality is vital to the processing industry, especially specific gravity, as recovery of the finished products is directly linked with this parameter. Therefore, while increasing the processing-grade tuber yield, it is essential that tuber quality does not deteriorate. Potato being a semi-perishable commodity, storage is inevitable to maintain the supply chain throughout the year. This requires assessment of tuber quality both at harvest and of the stored tubers. Since potato cultivars differ in their yield potential and quality traits (Belanger et al. 2002; Love et al. 2005), it is essential to evaluate every cultivar for its attributes. The objectives of this study were to determine (1) the N requirement of Chipsona cultivars for higher net income, and (2) the N rate and cultivar effects on processing quality at harvest and after storage.

Materials and Methods

Field Experiments, Description and Conditions

Field experiments were conducted during the 2000–2001 and 2001–2002 crop seasons at the Central Potato Research Institute Campus, Modipuram (29°4'N, 77°

46’E, 237 m asl) in a split-plot design with three replications, where N doses (0, 90, 180, 270 and 360 kg ha^{-1}) were assigned to sub-plots, and cultivars (Kufri Chipsona-1 and Kufri Chipsona-2) were allotted to the main plots. The soil of the experimental site was a deep, well drained, sandy loam soil (Typic Ustochrept). Chemical analysis of the soil (top 15 cm) showed a neutral pH (7.1), 0.28% organic carbon, 152 kg ha^{-1} potassium permanganate extractable nitrogen equivalent to 18–20 kg mineral N ha^{-1}, 37 kg ha^{-1} Olsen’s (0.5 M $NaHCO_3$ extractable) phosphorus, and 138 kg ha^{-1} exchangeable potassium. Half of the N (as per treatment), full P (52.4 kg P ha^{-1}) and K (99.6 kg K ha^{-1}) were applied at planting. The remaining half of the N was applied at the time of hilling (25 days after planting, DAP). N was applied through calcium ammonium nitrate at planting and through urea at hilling. P and K were applied through single super phosphate and muriate of potash, respectively. The experimental crop was planted on 28 October in 2000 and on 19 October in 2001. Well-sprouted seed tubers (50–60 g seed weight, about 40–45 mm seed size) were planted at a spacing of 60 × 20 cm (83,333 plants per ha) in plots of 4.8 m × 4 m. The experimental crop was raised under assured irrigation using the furrow method. Haulm killing was performed manually by removing the haulm at 110 DAP. Harvesting was done 2 weeks later after skin set in both seasons. Weather parameters were collected from the meteorological lab and are presented in Table 1.

Analysed Variables

Plant stand was monitored up to 30 days, while observations on growth parameters, such as plant height, compound leaf number and stem number, were recorded from five randomly selected potato plants from each plot at 50–55 DAP. Total and processing-grade (>45 mm tuber diameter) tuber yield and number were recorded at harvest from the whole produce of the plot. Fresh biomass yield (FBY) was calculated by adding the weight of fresh vines at the time of haulm killing to the fresh tuber yield (FTY). Representative sample of vines (100 g) was then dried in hot air oven at 70 °C until constant weight to calculate the dry matter concentration

Table 1 Monthly meteorological parameters during the crop seasons (growing periods: October to February)

Month	2000–2001					2001–2002				
	Monthly mean air temperature (°C)			Monthly BSS [a] (h)	Monthly rainfall (mm)	Monthly mean air temperature (°C)			Monthly BSS [a] (h)	Monthly rainfall (mm)
	Max.	Min.	Mean			Max.	Min.	Mean		
October	34.9	18.1	26.5	234.4	0.0	34.6	19.8	27.2	187.3	0.0
November	29.8	12.4	21.1	148.5	0.0	30.2	12.7	21.5	188.0	0.9
December	26.6	5.4	16.0	176.4	0.0	23.9	8.2	16.1	146.2	0.0
January	19.9	4.1	12.0	153.8	1.0	22.6	6.7	14.7	146.4	1.5
February	26.3	7.7	17.0	214.5	0.8	27.1	8.9	18.0	187.3	3.5

Source: Experimental meteorological station near the research farm. Temperature was recorded at 1 m height

[a] *BSS* Bright sunshine hours

of vines. Specific gravity was measured by the hydrometer method (Gould 1999) on 3.632 kg of processing-grade tubers from each plot.

Five tubers were selected randomly from each plot and used for determining the processing quality attributes dry matter percentage, crisps colour and reducing sugar concentration. Potato crisps were prepared at laboratory scale which involved peeling of the tubers in an abrasive peeler, slicing in 1.75-mm-thick slices with an automatic slicer, washing, and drying on a paper towel. Dried slices were fried in refined sunflower oil in a thermostatically controlled deep fat fryer at 180 °C until bubbling stopped. Fried crisps were then evaluated for crisps colour on a scale of 1–10, subjectively with the help of colour cards (Ezekiel et al. 2003), where 1 denotes a highly acceptable colour, 10 denotes a dark brown and unacceptable colour, and crisps with colour range of up to 3.0 are considered acceptable. Five tubers were chopped in fine pieces and a 10-g sample was taken for reducing sugars determination (Nelson 1944) and a 50-g sample was taken for tuber dry matter determination. Dry matter was determined by drying the whole samples in oven at 80 °C until constant weight was achieved. All determinations were carried out in duplicate. A sample of 30 processing-grade tubers from each plot was also stored at 10–12°C with two chlorocarbamate (CIPC, a sprout suppressant) foggings to investigate the effect of N doses on crisps colour after 5 months storage.

Agronomic N use efficiency (AE_N) was calculated by the following equation:

$$AE_N\left(\text{kg tuber kg}^{-1}\text{N applied}\right) = \frac{\text{FTY in fertilized plot} - \text{FTY in control plot}\left(\text{kg ha}^{-1}\right)}{\text{N applied}\left(\text{kg ha}^{-1}\right)}$$

The harvest index (HI), which is a measure of partitioning efficiency of dry matter to tubers was estimated according to Zvomuya et al. (2002):

$$HI = \frac{\text{Tuber dry matter}}{\text{Total dry matter}(\text{vines} + \text{tuber})}$$

Net income (NI) generated by a crop, was the amount of money which was left when total costs (TC) were subtracted from the total return (TR), which corresponds to the value of the harvested crop:

$$NI = TR - TC$$

Total returns were calculated by taking the price of the processing-grade potato tubers as 3,000 Indian Rupees (Rs.) Mg^{-1} (price paid by the processors to their contract growers during those years) and the price for non-processing grade potato tubers as 1,000 Rs. ton^{-1} (the prevailing market price for that quality of potato tubers). TC includes the costs of all inputs, such as seed potatoes, fertilizer, pesticides, labour and capital. The variable component in the total cost was nitrogen fertilizer, 17.90 Rs. kg^{-1} N. Benefit:cost ratio (B:C) indicates the returns one gets after investing one rupee. It was calculated by dividing the total returns with total costs of cultivation.

$$B{:}C = \frac{TR}{TC}$$

Analysis of Data

Data of each character collected from the experiments were statistically analysed using standard procedures of variance analysis with the help of statistical software IRRISTAT (IRRI 1999). The response to N was studied by fitting different (linear, logarithmic, quadratic) response equations for total tuber yield. The quadratic response equation had the best fit of the relationship between x and Y as shown below:

$$Y = a + bx + cx^2$$

In which Y = total tuber yield (t ha^{-1}); x = level of N fertilization (kg ha^{-1}); a, b and c = constants.

The economic optimum dose (EOD) of N (kg ha^{-1}) was computed by using the following equation:

$$X_{opt}(EOD) = \frac{(q/p) - b}{2c}$$

In which b and c are the two constants of the quadratic response equation for yield; q is the cost per unit of N and p is the price of one unit of total tuber yield.

The yield at the EOD of N was computed by using quadratic equation:

$$Y = a + bx + cx^2$$

In which Y = total tuber yield (t ha^{-1}) at EOD; x = EOD of N (kg ha^{-1}); a, b and c = constants of quadratic response equation.

The response to economic optimum dose (REOD) of N was computed by using the equation:

$$REOD = \frac{Y_{opt} - Y_{cont}}{X_{opt}}$$

In which Y_{opt} = Yield computed at the EOD; Y_{cont} = Yield in the control plot; X_{opt} = Economic optimum dose.

Results

Plant Emergence

Seed tuber emergence was recorded until 30 DAP in both cultivars (Table 2). The final emergence was more than 98% in all treatments and thus did not affect the evaluation of the cultivar response to different N levels in both years.

Growth Characters

The crop growth traits such as stem number, plant height and number of compound leaves were significantly higher during the 2001–2002 season. The above stated growth parameters responded positively to N fertilization, although the increase in stem number was statistically non-significant. The plant height increased with the

Table 2 Effect of year, cultivar and nitrogen rate on emergence, canopy characteristics and tuber number of potato crops

Treatment	Emergence (%)	Stem number per m^2 (50–55 DAP)	Plant height (cm) (50–55 DAP)	Compound leaf number per plant (50–55 DAP)	Tuber number at harvest (thousands ha^{-1})	
					Processing-grade	Total
Year (Y)						
2000–2001	99.1 a	40.5 a	55.5 a	70.9 a	266.1 a	605.7 a
2001–2002	98.7 a	45.9 b	81.0 b	92.1 b	415.2 b	663.8 b
Cultivar (C)						
Kufri Chipsona-1	99.1 a	40.9 a	61.3 a	76.2 a	382.6 a	698.3 a
Kufri Chipsona-2	98.7 a	45.5 b	75.2 b	86.8 a	298.7 b	571.2 b
Nitrogen (N) (kg ha^{-1})						
0	98.9 a	41.2 a	51.4 a	60.6 a	227.7 a	527.9 a
90	99.5 a	41.8 a	67.3 b	83.6 b	324.8 b	655.5 b
180	99.2 a	45.5 a	73.8 c	83.5 b	377.5 c	671.0 b
270	98.4 a	46.3 a	72.9 c	88.8 b	382.6 c	673.7 b
360	98.5 a	41.3 a	75.8 c	91.1 b	390.6 c	645.7 b
Analysis of variance						
Year	NS	**	**	**	**	**
Cultivar	NS	*	**	NS	**	**
Y × C	NS	NS	NS	NS	NS	NS
Nitrogen	NS	NS	**	**	**	**
Y × N	NS	*	NS	NS	NS	**
C × N	NS	NS	NS	NS	NS	NS
Y × C × N	NS	NS	NS	NS	NS	NS

DAP Days after planting; *NS* not significant, $P \geq 0.05$; *, ** significant at $0.01 \leq P < 0.05$ and $0.001 \leq P < 0.01$, respectively. Numbers followed by the same letter are not significantly different according to the Duncan's Multiple Range Test

increase in N dose up to 180 kg N ha^{-1}, whereas significant increase in number of leaves per plant was restricted to 90 kg N ha^{-1} only. Of the two cultivars, cv. Kufri Chipsona-2 showed the better growth characteristics, although significant differences were recorded only for stem number and plant height. Year × nitrogen interaction was significant for stem number, these being higher during the 2001–2002 season only in the control treatment (0 kg N). Interaction between N rate and cultivar was non-significant for all the growth characters studied, indicating that the two cultivars responded alike to increased doses of N (Table 2).

Tuber Number

Across all treatments, processing-grade and total tuber number were lower in the 2000–2001 season as compared to the 2001–2002 season. The response to N application was quadratic for processing-grade tuber number (R^2=0.986), total tuber number per ha (R^2=0.942) and tuber number per plant (R^2=0.953) (Table 2 and Fig. 1). Total tuber number per ha as well as tuber number per plant increased with increase in N dose up to 270 kg N; further increase in N dose resulted in a decline of both variables. On the other hand, the number of processing-grade tubers increased with increase in N dose up to the highest level, though the increase was only

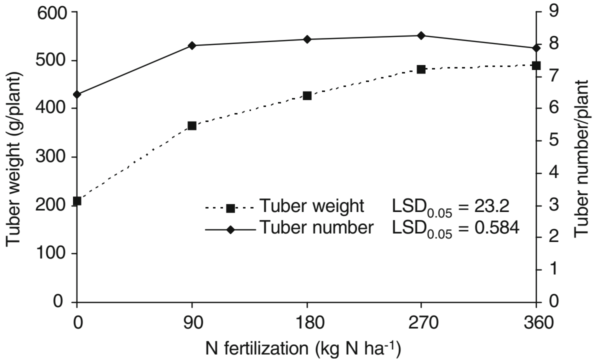


Fig. 1 Effect of N rate on tuber number and tuber weight per plant (means of cvs Kufri Chipsona-1 and Kufri Chipsona-2 during 2000–2001 and 2001–2002)

significant up to 180 kg N ha^{-1}. Processing-grade as well as total tuber number were higher in Kufri Chipsona-1 than Kufri Chipsona-2. Year × nitrogen interaction was significant for total tuber number, and showed that the tuber number was higher in the 2001–2002 season than in the 2000–2001 season at the 0 level of N only. The interaction between N rate and cultivar was not significant.

Tuber and Biomass Yield

Across all treatments, tuber yield, fresh biomass yield (FBY) and harvest index (HI) were significantly higher during 2001–2002. The response to N application was quadratic for tuber weight per plant (R^2=0.991), processing-grade tuber yield (R^2= 0.997), total tuber yield (R^2=0.990) and FBY (R^2=0.997) (Table 3 and Fig. 1). A significant increase in yield was, however, recorded only up to 270 kg N ha^{-1}. The economic optimum N doses for processing and total tuber yield were computed to be 304.6 kg N ha^{-1} and 334.2 kg N ha^{-1}, respectively. Total tuber yield and the response expected at the economic optimum dose were 42.6 Mg ha^{-1} and 76 kg tuber kg^{-1} N, respectively. The response of HI (or the proportion of total dry matter partitioned to tubers) to N fertilization was the reverse of that of tuber yield and FBY. Harvest index was similar when N dose was increased from 0 to 90 kg N ha^{-1}, and at higher levels every increase in N led to steady decline in HI. Cv. Kufri Chipsona-1 yielded significantly better in all respect than cv. Kufri Chipsona-2; the yield per plant was 23.6% higher (Fig. 2), the processing-grade yield 22.6% and the total tuber yield 24.3% (Table 3). The main effect of cultivar was non-significant for HI. Year × cultivar interactions were non-significant. This shows that both cultivars behaved similarly in both years. Year × nitrogen interaction was highly significant for HI, and showed that the HI was similar in both crop seasons at 0 kg N ha^{-1} only, whereas at other N levels, HI was higher in the 2001–2002 season than in the 2000–2001 season. The interactions between N rate and cultivar were not significant for tuber yield, FBY and HI.

Agronomic N Use Efficiency (AE_N)

AE_N did not differ significantly due to year and cultivar differences, whereas AE_N decreased linearly with the increase in N application (Fig. 3) and was 143 kg tuber

Table 3 Effect of year, cultivar and nitrogen rate on yield and economic parameters of potato crops

Treatment	Tuber yield (t ha^{-1})		Biomass yield (Mg ha^{-1})	Harvest index	Net income (Rs. ha^{-1})	B:C ratio (Rs. Rs.$^{-1}$)
	Processing-grade	Total				
Year (Y)						
2000–2001	19.2 a	26.7 a	32.6 a	0.87 a	21,757 a	1.48 a
2001–2002	33.1 b	38.0 b	45.7 b	0.93 b	61,041 b	2.39 b
Cultivar (C)						
Kufri Chipsona-1	28.8 a	35.8 a	42.8 a	0.90 a	50,175 a	2.14 a
Kufri Chipsona-2	23.5 b	28.8 b	34.1 b	0.90 a	32,623 b	1.73 b
Nitrogen (N) (kg ha^{-1})						
0	11.9 a	17.2 a	18.2 a	0.92 a	1,089 a	1.03 a
90	22.9 b	30.1 b	33.0 b	0.92 a	34,379 b	1.83 b
180	28.7 c	35.1 c	41.2 c	0.90 b	49,192 c	2.14 c
270	33.0 d	39.2 d	48.8 d	0.88 c	60,392 d	2.35 d
360	34.2 d	40.0 d	51.1 e	0.87 c	61,944 d	2.33 d
Analysis of variance						
Year	**	**	**	**	**	**
Cultivar	**	**	**	NS	**	**
Y × C	NS	NS	NS	NS	NS	NS
Nitrogen	**	**	**	**	**	**
Y × N	NS	NS	NS	**	NS	NS
C × N	NS	NS	NS	NS	NS	NS
Y × C × N	NS	NS	NS	NS	NS	NS

DAP Days after planting; *NS* not significant, $P \geq 0.05$; *, ** significant at $0.01 \leq P < 0.05$ and $0.001 \leq P < 0.01$, respectively. Numbers followed by the same letter are not significantly different according to the Duncan's Multiple Range Test

kg^{-1} N at 90 kg N ha^{-1}, which decreased to 63.2 kg tuber kg^{-1} N at the highest N dose (360 kg N ha^{-1}).

Processing Quality Parameters

Across all treatments, tuber specific gravity and tuber dry matter percentage were lower in 2001–2002 than in 2000–2001. Both variables responded positively when the N rate was increased from 0 to 90 kg N ha^{-1}, and thereafter did not increase significantly any further (Table 4). Cv. Kufri Chipsona-2 (1.090) had a significantly higher specific gravity than cv. Kufri Chipsona-1 (1.087), but the dry matter percentage was statistically the same in both cultivars. Year × cultivar interactions showed that specific gravity and dry matter percentage were lower in the 2001–2002 season than in the 2000–2001 season only in cv. Kufri Chipsona-1, and not in cv. Kufri Chipsona-2. Interaction between N rate and cultivar was also highly significant for specific gravity and indicated that increase in specific gravity with N application was recorded up to 180 kg N ha^{-1} in cv. Kufri Chipsona-1, while the increase in the specific gravity was observed up to 270 kg N ha^{-1} in cv. Kufri Chipsona-2.

Crisps colour (both at harvest and after 5 months storage) and reducing sugar concentration were significantly lower—as preferred—in the 2001–2002 season compared to 2000–2001. Both variables were not markedly influenced by different N rate in the current study (Table 4), but there was slight deterioration in colour of

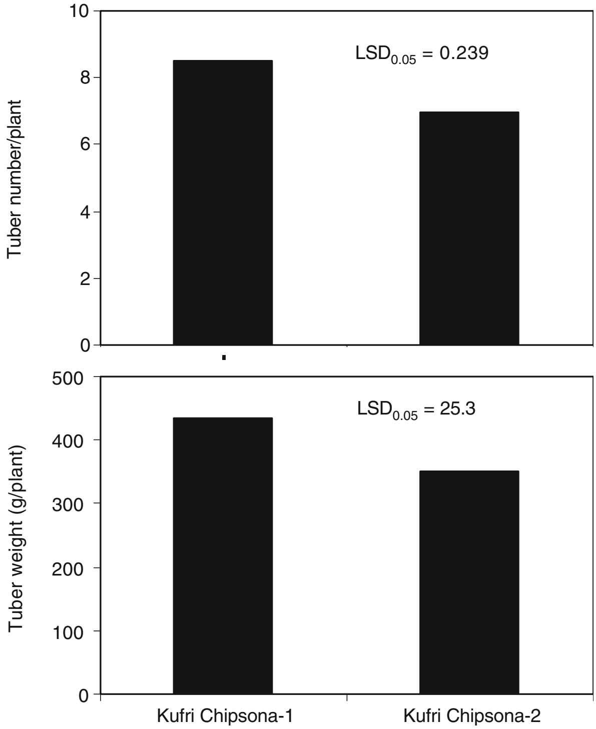


Fig. 2 Effect of cultivar on tuber number and tuber weight per plant (means over N rates during 2000–2001 and 2001–2002)

the crisps from stored potatoes as compared to crisps from freshly harvested tubers across the N rates. Crisps colour, both at harvest and after storage, was significantly higher in cv. Kufri Chipsona-2 than in cv. Kufri Chipsona-1. Reducing sugar concentration was not influenced by the cultivar. Interactions between year, N rate and cultivar were not significant for crisps colour (at harvest and after storage) and reducing sugar concentration.

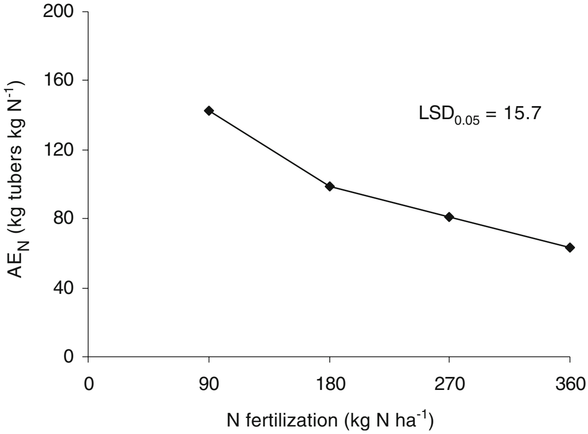
Economics

Analysis of variance showed significant year, N rate and cultivar effects for net income and benefit cost ratio (B:C) (Table 3). Net income and B:C ratio were higher in 2001–2002 than in 2000–2001. The response to N rate was quadratic for net income (R^2=0.994) and B:C ratio (R^2=0.991). Net income and B:C continued to increase significantly untill 270 kg N ha^{-1}. Cv. Kufri Chipsona-1 gave a significantly higher net income and B:C ratio (Rs. 50,175 ha^{-1} and 2.14) than cv. Kufri Chipsona-2 (Rs. 32,623 ha^{-1} and 1.73). Interactions between year, N rate and cultivar were not significant for the economic variables.

Discussion

Variations in weather parameters between two seasons, 2000–2001 and 2001–2002, influenced almost all the variables studied. Higher growth, yield and net income

Fig. 3 Effect of N rate on Agronomic N use efficiency (AE_N) (means of cvs Kufri Chipsona-1 and Kufri Chipsona-2 during 2000–2001 and 2001–2002)



were recorded in 2001–2002 than in the year 2000–2001 (Tables 2 and 3). The experimental crop during 2000–2001 was planted slightly later (28 October) than the optimum planting period (15–25 October), which might have adversely affected the overall crop productivity. A higher number of bright sun shine (BSS) hours (188.0) during November 2001 (Table 1) coincided with the tuber initiation and the

Table 4 Effect of year, cultivar and nitrogen rate on processing quality of potato tubers

Treatment	Specific gravity	Tuber dry matter (%)	Crisps colour score[a] at harvest	Crisps colour score after storage[b]	Reducing sugar concentration (mg 100 g^{-1} FW)
Year (Y)					
2000–2001	1.091 a	23.2 a	3.3 a	3.6 a	38.3 a
2001–2002	1.086 b	22.1 b	2.0 b	2.4 b	22.2 b
Cultivar (C)					
Kufri Chipsona-1	1.087 a	22.7 a	2.4 a	2.9 a	30.2 a
Kufri Chipsona-2	1.090 b	22.6 a	2.9 b	3.1 b	30.4 a
Nitrogen (N) (kg ha^{-1})					
0	1.086 a	21.9 a	2.5 a	3.0 a	24.5 a
90	1.089 bc	22.7 ab	2.7 a	3.0 a	24.5 a
180	1.090 b	23.1 b	2.9 a	3.0 a	33.5 a
270	1.089 bc	23.0 b	2.7 a	3.0 a	36.5 a
360	1.088 c	22.6 ab	2.6 a	3.0 a	32.5 a
Analysis of variance					
Year	**	**	**	**	*
Cultivar	*	NS	**	*	NS
Y × C	**	*	NS	NS	NS
Nitrogen	**	*	NS	NS	NS
Y × N	NS	NS	NS	NS	NS
C × N	**	NS	NS	NS	NS
Y × C × N	NS	NS	NS	NS	NS

DAP Days after planting; *NS* not significant, $P \geq 0.05$; *, ** significant at $0.01 \leq P < 0.05$ and $0.00 \leq P < 0.01$, respectively. Numbers followed by the same letter are not significantly different according to the DMRT test

[a] Low = preferred colour

[b] Storage at 10–12°C with CIPC fogging for 5 months

establishment of the crop canopy. Growth of crop canopy is known to be hastened by a high amount of radiation which is primarily due to the effects on axillary branch formation. Therefore, favourable conditions during early haulm growth in 2001–2002 resulted in a large haulm surface (higher stem number, higher plant height and higher leaf number), and maintained tuber growth at a higher rate for a longer time period leading to higher yield (Moorby and Milthorpe 1975). During December of the 2000–2001 crop season, the daytime maximum temperature was considerably higher (26.6 °C) than during the 2001–2002 season (23.9 °C). A high day temperature is usually associated with a high rate of respiration and transpiration, leading to moisture stress even when soil moisture content is high. Rate of net photosynthesis has been reported to decrease when day temperature is higher than 25 °C (Horton 1987).

A higher N fertilization had a positive effect on plant growth parameters (Table 2), and increased tuber number and yield (Tables 2 and 3). Similar results were obtained by Rai et al. (2002) with respect to plant height and stem number. However, both positive and negative effects of N application on tuber number per plant have been reported (Sommerfeldt and Knutson 1968; Morena et al. 1994; Belanger et al. 2002). Processing-grade and total tuber number were higher for cv. Kufri Chipsona-1 than for cv. Kufri Chipsona-2 (Table 2). The phenomenon of tuber setting is mainly governed by the genetic make up of the cultivar (Horton 1987); consequently, cultivars differ with regard to tuber number per plant. The increase in total tuber yield due to higher N application was because of higher crop growth leading to more synthesis and translocation of photosynthates to the tubers by the foliage. An increase of potato tuber and fresh biomass yield by N fertilization has also been reported by Belanger et al. (2000) and Sharma and Dubey (2000). When N dose was increased from 0 to 90 kg N ha^{-1}, HI remained the same. At higher N doses, every increase in N level resulted in a commensurate decline in HI (Table 3). This suggests that vine growth was favored over the tuber growth at high N doses (Zvomuya et al. 2002). AE_N decreased linearly with every incremental dose of N, which confirms earlier results (Zvomuya et al. 2002; Love et al. 2005).

Nitrogen is indirectly related to potato tuber quality, via its effect on dry matter concentration and relative maturity of the harvested tubers (Westermann et al. 1994a). The tuber dry matter increased from 0 to 180 kg N ha^{-1} with increase in N fertilization. Thereafter the differences were not significant (Table 4), which is consistent with other findings (Lauer 1986; Westermann et al. 1994b; Joern and Vitosh 1995). Specific gravity was higher for cv. Kufri Chipsona-2 (1.090) compared to cv. Kufri Chipsona-1 (1.087). Besides tuber dry matter/specific gravity, crisps colour is another indispensable quality trait which affects the consumer preference. A positive correlation between crisps colour and reducing sugars concentration has been reported (e.g., Ezekiel et al. 2003). There are conflicting reports on the effect of N doses on crisps colour and reducing sugars. Silva et al. (1991), Kumar et al. (2002) and Long et al. (2004) did not observe any adverse effect of N doses on crisps colour and reducing sugars. Results obtained in the present study are consistent with these findings. However, Iritani and Weller (1978) recorded lower concentration of reducing sugars at harvest under optimum N dose.

Higher economic returns and B:C ratio were obtained at higher N doses (Table 3). This was due to the higher processing and total tuber yield realized at higher N application. These results are in partial agreement with the findings reported by Love et al. (2005), who reported that net returns were relatively low when no N was applied; rose to a highest level at some intermediate rate, and then fell again at the highest N rate(s).This study also demonstrated the profitability of cultivation of cv. Kufri Chipsona-1 over Kufri Chipsona-2 as net returns were appreciably higher with cv. Kufri Chipsona-1.

The present study indicated that newly developed Indian processing cultivars responded to 270 kg N ha^{-1} to a level of statistical significance without reduction in processing quality. However, the economic optimum dose of N for processing grade and total tuber yield was even higher than 270 kg N. However, because N is highly mobile in the soil system and keeping the possible leaching losses in mind, 270 kg N ha^{-1} is being suggested to Chipsona growers. Further studies should quantify the N losses especially in ground water at the suggested and economic optimum dose of N.

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