June 2009 Volume 3 Issue 3

Trade Science Inc.

BioTechnology
An Indian Journal
REVIEW

BTAIJ, 3(3), 2009 [116-124]

Short-day onion improvement program in India for producing dehydrated products

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Received: 8th April, 2009 ; Accepted: 13th April, 2009

ABSTRACT

Onions are preferred all over the world as vegetable, salad and accompaniment of food, being eaten fresh, dehydrated, frozen, pickled, stewed, roasted and fried in different shapes and sizes for taste and flavor in several preparations at home and recipes of processed foods in industry, besides recent therapeutic use as nutraceuticals. Desirable attributes of onions for dehydration industry are given along with a schematic diagram for dehydration. The emergent dehydrated onion products are displayed along with their nutrient composition and specifications for permissible level of microbial contaminants to ensure safety of human beings after consumption. Significance of high TSS, flavor and pungency is narrated, highlighting methods of TSS and pyruvic acid estimation. On this background short-day onions are discussed, being the prevalent variety in India for local consumption and export, in the context of state-wise productivity, year-wise export volumes vis-à-vis realization, heterogeneity of cultivars and factors influencing their size, pungency, bolting and doubling are given, which are likely to influence their varietal improvement program in India. Thus, this brief review sets a stage focusing on constraints in improvement and targeted parameters desired from improvement.
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KEYWORDS

Short-day;
Onion improvement;
Desired attributes;
Needs of dehydration industry.

INTRODUCTION

Onions are preferred all over the world as vegetable, salad and accompaniment with food. Hence, they are under cultivation on an area of 3.45 million hectares (MHa), providing 64.47 million metric tons (MMT) production and thereby globally ranked second in value on the list of cultivated vegetable crops[1]. In the world, China is the largest (19.3%) producer, followed by India (17.8%), while Republic of Korea has highest productivity of 62.5 ton/ha on global scenario (TABLE 1)[2].

However, onions are also grown in 126 countries, of which about 62% of the world's production is from the Asiatic countries[2], where short-day onions are grown. Storage and transportation of these onions from producers to consumers being a major problem, huge demand for its processing has been created.

1. Onions are versatile, being eaten raw, stewed, roasted or fried

Onions are one of the oldest vegetables known to mankind, used for their flavor, aroma and taste. They

TABLE 1: Area under cultivation, production and productivity of onion in the world

Sr. no.	Onion	Area (MHa)	Production (MMT)	Productivity (Tons/ha)
1	World	3.45	64.47	18.68
2	China	1.00	20.55	20.53
3	India	0.61	08.17	13.20
4	USA	0.064	03.60	55.88

are used (i) in vast number of recipes and preparations, spanning world's almost all cultures, (ii) in fresh, frozen, canned, pickled and dehydrated forms and (iii) usually chopped or sliced, in almost every type of food, including fresh salads, cooked foods, as a spicy decoration and an accompaniment to the main course[3]. Depending on the variety, an onion can be spicy and pungent or mild and sweet. Besides, they are preserved domestically or industrially as a raw material for a variety of food manufacturing processes such as dehydration, freezing, canning and pickling. In fact, onions were one of the earliest (since 1941) established dehydrated vegetables and widely used in the manufacture of other processed foods[4].

1.1 Onions as functional food

The Institute of Medicine's Food and Nutrition Board[5] defined functional foods as "any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains"[6].

1.1.1. Uses in mediterranean

"Let food be thy medicine and medicine be thy food" was believed by Hippocrates nearly 2,500 years ago; this theme is receiving renewed interest now under the term neutraceuticals[7]. Bulbs from the onion family have been used from the millennia as a common food as well as in the treatment of many diseases[8]. The first citation in this regard is found in Codex Ebers (1550 BC), where an Egyptian medical papyrus has reported several therapeutic formulae based on onions as useful remedy for simple to complex diseases such as headache, bites, worms, problematic hearts and tumours[9]. Egyptians thought that onions aided in endurance and hence consumed in large quantities. In ancient Greece too, presumably for the same reason, athletes ate large quantities of onion. Raw plants were routinely given to asthmatics and individuals suffering from bronchial-pulmonary complaints[10]. Roman gladiators were also rubbed down with onion to firm up their muscles. Later on, Greeks and Romans used them as important healing agents. Even today, they are used for the same purpose by most of the people in the Mediterranean area[11].

1.1.2. Uses in India

Here, (i) traditionally onions are used for the treatment of fever, dropsy, catarrh and chronic bronchitis, (ii) raw onion has an antiseptic value throughout the alimentary canal, fresh onion juice being moderately bactericidal, (iii) warm juice is dropped into the ear to relieve ear-ache, (iv) onions are eaten with refined sugar to stimulate growth of children, (v) mixed with vinegar, onions are used to treat sore throat, (vi) cooked with vinegar, they are consumed in jaundice, splenic enlargement and dyspepsia, (vii) eaten twice/ day in malarial fevers with a remarkable relief[12], (viii) its essential oil (0.05% of the bulb) contains a heart stimulant, increases pulse volume and frequency, restores systolic pressure, coronary flow, stimulates smooth musculature in intestine and uterus and (ix) it promotes bile production and reduces blood sugar[13].

Modern medical research has confirmed that (a) onions contain as many as 150 phyto-chemicals, (b) a flavonoid, quercetin, an anti-oxidant (phyto-chemical) found in onions, scavenges free radicals in the body, inhibits oxidation of low-density lipoproteins, protects/ regenerates vitamin E and helps to circumvent harmful effects of heavy metal ions, (c) other sources of quercetin are tea (*Camillia sinesis*) and apple (*Malus domestica*); but research has shown that absorption of quercetin from onions is twice that from tea and more than thrice that from apples (http://health.learninginfo.org/onion-nutrition.htm), (d) anti-asthmatic, anti-diabetic and anti-platelet activities exist in onion and (e) daily intake of 50-100 g onions is recommended to take utmost advantage of beneficial therapeutic effects[14].

2. Onion products

United States is the leading country in onion cultivation and processing, where onion is processed in the form of pickled onion (in brine and acetic acid). For processing, bright white onions, which are fully cured and free from external damage, fungi, bacterial spores, sprouting and greening are used[15].

Globally, important cultivars for dehydration include White Creole, Southport White Globe, Dehydrator No. 8 and Dehydrator No. 14[15], which are long-day or intermediate-day length type. Long-day or intermediate-day length type cultivars are not able to form bulb

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TABLE 2: Desirable attributes in onions for dehydration industry

1	Adaptability to *kharif* (rainy season) and *rabi* (winter season)
2	Good resistance to biotic and abiotic stresses
3	Resistance to bolting during bulb production
4	Minimum % of doubles
5	Small basal plate
6	Thin neck
7	Outer tough dry skins
8	High yields
9	Good transport resistance
10	High total soluble solids (>20%)
11	High insoluble solids
12	Snow white shining colour
13	Good storage quality
14	Long dormancy
15	Free from greening
16	High degree of pungency
17	Low reducing: non-reducing sugars to avoid caramelization
18	Good flavour

TABLE 3: American dehydrated onion and garlic association quality standards and grade specifications

Product	Colour (optical index)	Bulk index (ml/100 g)	
		Minimum	Maximum
Sliced	90	400	-
Large chopped	90	300	-
Minced	90	150	220
Granulated	105	110	180
Ground	90	120	180
Small chopped	90	180	245
Chopped	90	180	280
Special large chopped	90	270	-
1/4" Diced	90	240	310

under short-day length conditions. White onion varieties for the processing units with important attributes are summarized in TABLE 2.

Freshly harvested bulbs as well as stored bulbs are used for dehydration. During harvesting, handling and storage, the bulbs carry a heavy load of harmful bacteria, fungi and yeast. There is every possibility of passing these microbes to the final product. Therefore, utmost care is exercised to reduce them by peeling outer 2-3 layers, de-rooting and surface sterilizing before cutting and dehydration. van Arsdel et al.[16] have given a schematic representation of the flow diagram for onion dehydration in figure 1[16].

Traditionally onion dehydration is performed on a domestic scale by sun-drying in India. Various types and capacities of solar driers have also been designed

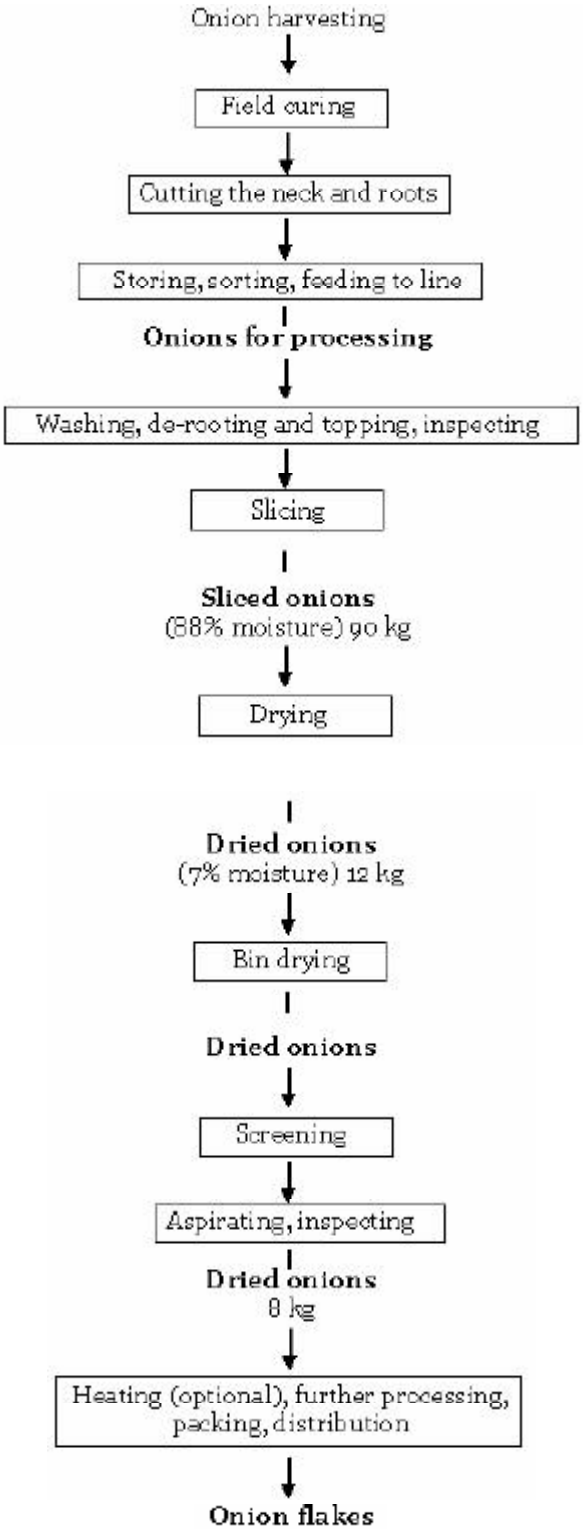

Figure 1: Onion dehydration flow diagram

for dehydration. However, controlled drying under optimum temperature and time gives the quality product. Dehydration is preceded by removal of outer skin, roots and woody portion to reduce microbial load. Com-

TABLE 4: Nutrient composition of dehydrated onion

Sr.no.	Nutrient	Content (%)
1	Carbohydrates	75.7
2	Protein	10.1
3	Fiber	5.7
4	Ash	3.2
5	Fat	1.1
6	Moisture	5.0
7	Energy (Kcal)	347
Sr. no.	**Trace elements**	**mg/ 100 g**
1	K	943
2	Ca	363
3	P	340
4	Mg	122
5	Na	54
6	Fe	3
7	Zn	2
Sr. No.	**Vitamin**	**mg/ 100 g**
1	Ascorbic acid	0.015

mercial dehydration is achieved under hygienic conditions by forced hot air with the total process divided into three stages: drying at 75, 65 and 55-60^{0}C, the temperature and duration of dehydration becoming lesser as the moisture content falls from 82% to about 5%.

Dehydration is considered complete when the final moisture content (~4%) is achieved by circulation of warm air currents. While appearance of the dehydrated products being taken as a reflection of optimized conditions for drying, the process needs to be completed in minimal period to avoid partial caramelization of free sugars in onion. This is possible in onions with high (18-26%) TSS, where dehydration is rapid with the removal of 72-78% moisture.

Dehydrated products

Onion is dehydrated in the form of flakes, rings, kibbles and powder (Figure 2).

The American Dehydrated Onion and Garlic Association has given standardized quality and grade specifications for dehydrated onion products[17]. Based on particle size the products are classified as shown in TABLE 3.

In all products, moisture is not more than 5.0 % and they should be free from (i) metallic particles, (ii) hair, (iii) extraneous vegetable/ woody matter, (iii) seed stems, (iv) black or dark brown onion pieces due to excessive heating, (v) sediment attached to onion and (vi) roots. The dehydrated products are fortified with commercially available anti-caking agents, packed in

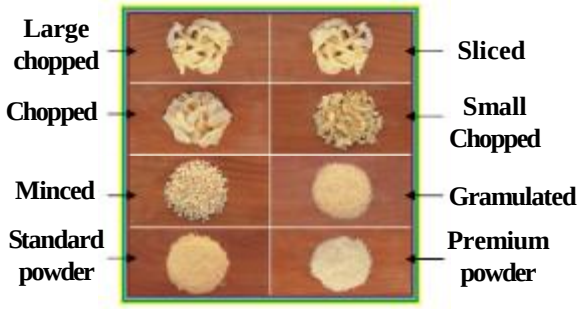

Figure 2: Onion dehydrated products

polythene bags, placed in fiber drums so as to protect them from moisture and photo-oxidation. For this purpose, the dehydrated products are stored under cool and dry conditions, away from light, since high temperature (above 15^{0}C) and exposure to light reduce their colour quality by partial yellowing.

As a matter of principle, the products should be totally free from any pathogen, beyond doubt. The count of other microbes is limited to levels, which ensure human safety upon consumption, as prescribed by Prevention of Food Adulteration & Food Product Order (PFA & FPO):

Microbe	Permissible contamination/ gm
Total viable count	< 100,000
Yeast and mould	< 500
Coliforms	< 100
Salmonella	Not detected
E.coli	Not detected

Nutrient composition of dehydrated onions is shown in TABLE 4.

A large part of dehydrated onion products are used as seasoning in the production of ketchup, chili sauce, meat casseroles, cold cuts, sauces, soup, mayonnaise, salad dressing, sweet pickles, pet food, potato chips, crackers and other snack items. Food servicing outlets also use dehydrated onion because of its convenience in storage, preparation and use[18].

3. Important attributes of onions for processing

Systematic breeding programmes for the development of high TSS white onion varieties are launched by Agriculture Universities, various research organizations, seed companies and dehydration industry in the United States, China and India. These programs are the backbone of the dehydration industry, as high TSS (i) has less moisture for dehydration, (ii) requires less energy and (iii) needs less dehydration time, which in turn gives

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white (rather than yellowish) products. Development of suitable varieties in short-day onions grown in Asiatic countries too hold good promise with the available indigenous and exotic inputs to develop hybrid onion varieties, which have the attributes desired by the dehydration industry (TABLE 2).

3.1. Total soluble solids (TSS) and pungency

Onion bulb is a food storage organelle for flower and seed production. Its fleshy structure is made up of concentric scales, which contain simple and complex sugars, sulphur- and nitrogen-containing flavor precursors and considerable amount of moisture in the turgid cells. The bulb is protected against (i) fungal infection by a group of water-soluble phenolic compounds, protocatechuic acid and catechol[19], (ii) decay during the resting/ storage period by outer dry papery scales, while basal plate is protected by a corky outer layer[20] and (iii) moisture loss by tight neck closure and low rate of respiration[21].

Though different methods to measure solidity and dry matter content of bulbs were examined and correlation coefficients between different characters calculated, no strong correlations were found between the results of different methods of measuring solidity. On this background, Mann and Hoyle (1945)[22] were the first to use refractometer for predicting dry matter content of onion juice on the basis of its refraction value, which gave a reliable estimate of the dry matter content of onion bulb[23].

3.1.1. Dry matter composition of onions

Fluctuations in dry matter content are extensively studied by Fenwick and Hanley (1985, 1990a)[24,3]. Onion contains non-structural carbohydrates that include glucose, fructose and sucrose, together with a series of oligosaccharides, the fructans[25]. Low molecular weight fructans up to 9 DP (degree of polymerization) are absent in outer, older bulb scales, but present in an increasing amount from outer to inner bulb scales. In contrast, free fructose concentration was highest in outer scale, but lowest in innermost scale, while glucose and sucrose did not change across the bulb[6].

3.1.2. Preference for dry matter by dehydration industry

Table onions preferred from fresh market have low (9-13%) dry matter content. In contrast, cultivars preferred by the dehydration industry have dry matter above 20%. Comparison between cultivars of low, medium and high dry matter content showed that (i) low dry matter cultivars have high glucose, fructose and sucrose levels and only traces of fructans, (ii) medium dry matter cultivars have lower glucose, fructose and sucrose levels, but high amount of fructans and (iii) the same trend persists in high dry matter onions[6].

3.1.3. Basis of onion flavor and pungency

Onion juice contains sulphur-containing organic compounds, which constitute pungency. When onion tissue is damaged, an enzyme allinase present in the vaccuoles of cells oozes out. It hydrolyzes alkyl or alkenyl cysteine sulphoxides held in the cytoplasm[26], forming various sulphides, which constitute onion flavors[24] and pyruvic acid as a byproduct of hydrolysis. Therefore, pyruvic acid is taken as an approximate indicator to onion pungency and enzymatically produced pyruvate to compare pungency in different cultivars in a number of studies. As a matter of enhancing the reliability of pyruvic acid estimates, modification to (a) commonly used procedure for pyruvic acid estimation in onions[27] and (b) elimination of interference from pigments in yellow onions led to (i) changes in concentrations and volumes of the reagents and (ii) use of 515 nm rather than 420 nm as an absorption maxima for estimation[28].

3.1.4. Pungency as a function of onion cultivar

Over 95% of pyruvic acid is produced in onion tissue within 6 minutes after its disintegration. Its total amount produced appears to depend on the degree of onion pungency. While weak onions produced 2-4 μmoles, intermediate strength onions produced 8-10 μmoles and strong onions 15-20μmoles of pyruvic acid per g[27]. Thus, a highly significant correlation (r=-0.97) exists between the amount of enzymatically produced pyruvic acid in onion juice and its olfactory threshold concentration. This correlation indicated that determination of pyruvic acid in a freshly prepared onion juice constituted a fairly simple, reliable and convenient method of estimating onion flavor too[29].

3.1.5. Pungency as a function of genetic and environmental factors

To determine the effect(s) of genetic and environmental factors on onion pungency on the basis of pyruvic acid levels, genetically identical clones grown at three different locations and greenhouse showed that onion pungency was significantly influenced by (a) clone type,

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(b) location of growth (which determined 11.4% of total variation) and (c) their interaction(s). It was observed that genetic differences alone determined 81.3% of total variation, location (including all environmental factors) and clone × location interaction determined 11.4 and 7.3% of the total variation, respectively. The pungency levels were (i) not positively correlated with soil sulfur levels in 16-97 ppm range, (ii) loosely inversely correlated within clones with increasing bulb weight, (iii) uniform (8% CV) in the clones, followed by hybrids (10.6% CV) and open-pollinated cultivars (21.3% CV) and (iv) influenced by environmental factors to a lesser degree. Therefore, choosing cultivars with low pungency, ideal growing environment and proper sulfur nutrition control, are key factors in producing sweet onions[30].

4. Short-day onions in India

All onions are physiologically long-day plants. However, mechanism that controls onion bulbing is really a phytochrome response to the length of night. Therefore, in short-day (SD) onions grown in tropics, bulbing is induced in response to night lengths, which are relatively long, at around 12 hours. Intermediate-day (ID) and long-day (LD) cultivars grown at higher latitudes are induced to form bulbs by nights that are relatively shorter (8-11 hours), corresponding to days of 13 -16 hours[31].

4.1. Creole onions in tropics

'Creole' is a traditional onion of Louisiana State (USA), now grown in tropical countries too as it (i) has tolerance to purple blotch, (ii) fulfills needs for moderate-sized, pungent onions and (iii) gives reasonable yields. Waxy layer on their leaves presumably provides better tolerance to hot conditions and attack by biotic factor(s). As a result, mature Creole bulbs have (a) several tough dry skins, (b) good transport resistance, (c) long dormancy and (d) reasonable storage life (4-5 months) under hot conditions[31]. Since Creole selections ('Creole Red PRR PVP' from Sun seed; 'Creole Red PRR' from Peto) with improved pink-root disease-resistance exist, White Creole has provided the basis for the development of short-day dehydration onions by virtue of relatively high dry matter content[31].

TABLE 5: State-wise onion production in India (NHRDF, 2007)

Sr. no.	State	Area ('000 ha)	Yield (Ton/ha)	Production (in '000 MT)
1	Gujarat	52.45	21.23	1,113.48
2	Maharastra	116.02	21.1	2,448.27
3	Haryana	13.74	19.73	271.05
4	Rajasthan	30.13	15.02	452.42
5	Madhya Pradesh	26.29	13.1	344.3
6	Bihar	27.66	11.08	306.43
7	Uttar Pradesh	60.38	10.46	631.38
8	Tamil Nadu	27.2	10.19	277.11
9	Andhra Pradesh	21.93	9.12	199.93
10	Orissa	57.3	8.72	499.45
11	Karnataka	57.39	7.93	455.11
12	Others	37.26	12.12	451.59

4.2. Onions in India

4.2.1. Onion productivity

Since 1950, older onion cultivars (Nashik Red', 'Bombay White', 'Poona Red' etc.), christened after districts of their origin, were used for cultivation. Even though onion research started in India since 1950, an average yield has been less than 11 tons/ha, probably the lowest among the major onion producing countries. While cultivation (i) during *kharif* and (ii) under short-day condition has been partly responsible for lower yields, it is equally true that (a) improvement in varieties, (b) sustainable inputs and (c) good agronomic management practices are needed to raise the yields. Most varieties grown in India are open pollinated and hybrid seed production using cytoplasmic male sterile (CMS) lines has not been fully exploited[32].

4.2.2. State-wise scenario

India ranks second in onion bulb production (8.1 MMT), with second largest area under cultivation (0.61 MHa).[1] In India, Maharashtra (i) is the largest producer of onions (2.44 MMT), (ii) has largest cultivation area (116,020 hectares) and (iii) onion productivity is slightly lower (21.1 tons/ha) than in Gujarat (21.23 tons/ha) (TABLE 5)[33].

4.2.3. Exports

Export of onions from India during 2005–06 was 0.78 MMT, valued at Rs. 71,59 million /-[34]. Export data (TABLE 6) has shown that with each passing year, onion export has grown tremendously[35].

Besides fresh onions, India also exported dehydrated onion (4124 tons) and processed onion (9095 tons), worth Rs.178.11 million and Rs. 191.85 million, respectively[15]. In fact, the export of dehydrated on-

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TABLE 6: Export of onions from India (NHRDF, 2008)

Year	Quantity (Tons)	Rate (Rs/Ton)	Realization (Million US $)
1951-1952	56,986.00	187.22	0.24
1961-1962	114,023.00	255.47	0.65
1971-1972	54,866.00	414.76	0.51
1981-1982	169,771.00	1,733.99	6.54
1991-1992	406,135.00	4,012.67	36.22
2001-2002	506,924.00	8,115.72	91.42
2002-2003	545,211.00	7,101.60	86.04
2003-2004	840,717.00	9,768.16	182.49
2004-2005	941,448.00	8,683.34	181.66
2005-2006	778,134.00	9,201.08	159.10
2006-2007	1,161,062.00	9,779.22	252.32
2007-2008	1,101,404.00	11,674.43	285.74
2008-2009	867,001.00	8,441.82	162.65

ions touched 12567 tons, worth Rs. 542.2 million during 2003 -04[36]. To our knowledge, export has almost doubled (25,000 tons), crossing the realization of Rs. 1000 million during 2007-08.

4.2.4. Heterogeneity of cultivars

For onion production, many Indian farmers use their own seed, which has given rise to high genetic diversity. Due to cultivation of different onion cultivars or locally named land races, adapted to local environment, highly heterogeneous onion population exists in India. To conserve these varieties for posterity, National Bureau of Plant Genetic Resources Gene Bank, New Delhi has collected large accessions[37].

4.2.5. Regional influence on onion bulb size

Onion crop is taken during either *rabi* season (winter about 11-12 hr photo-period) or *kharif* season (monsoon, 11-12 hr photo-period) to which cultivars are well adapted[31]. Onions grown in South India tend to be smaller than the northern cultivars. For example, (i) Bangalore Rose onion of 25-30 mm in diameter, categorized as small, is grown mainly in Karnataka and Andhra Pradesh[38], (ii) cultivars grown in Maharashtra, Gujarat, Uttar Pradesh, Haryana, Madhya Pradesh, Rajasthan and Punjab, grouped in big category, yield flat to round shaped, medium-sized (40-65 mm diameter), pungent onions.

4.2.6. Varietal improvement

In order to promote onion improvement with export potential, Associated Agricultural Development Foundation (AADF) was set up in 1977, which was later rechristened as National Horticultural Research and Development Foundation (NHRDF), Nashik. In Maharashtra, this institution has developed cultivars (i) Agrifound Light Red (*Rabi*), (ii) Agrifound Dark Red (*Kharif*), (iii) Agrifound White (dehydrator) and (iv) Agrifound Red (multiplier onion) for export. Arka series of improved cultivars were developed by Indian Institute of Horticultural Research (IIHR), Bangalore. Tamil Nadu Agricultural University (TNAU), Coimbatore, has bred multiplier onions[39]. Onion breeding in India is compiled by Pathak and Gowda (1994)[40], Pathak (1999)[41] and finally updated by Gupta and Bhonde (2006)[42]. In the mean time, Singh (1998)[43] found that seed availability of improved Indian-bred cultivars was not adequate to meet the demand. Almost all Indian cultivars possessed TSS in 11-13° brix range[32] or below 15° brix[44-46]. Studies on exotic onions have also not shown any promising cultivars[47,48]. In view of these studies, Pandey (2002)[49] has stressed the importance of high TSS for the Indian onion dehydration industry.

Presently, ICAR, Agricultural Universities and R&D centers of dehydration industry are working on onion breeding. Varietal improvement through classical breeding procedures, aided by biotech approaches such as marker-assisted breeding is essential not only for better yields, but also for several desirable characteristics such as (i) resistance to disease, (ii) resistance to abiotic stresses, (iii) bulb quality parameters, etc. Although plant breeders in India have released several varieties, they possess undesirable characters of high bolting, doubling etc. Secondly, white onion varieties released for processing have relatively low TSS (13%) as compared to some of the exotic open-pollinated varieties and F_1 hybrids (18-26%).

4.2.7. Nuisance of bolting

Bolting (formation of cellulosic, woody, non-edible structure in the centre of onion) is a general problem during bulb production under field conditions. Several cultivars produce bolting to the extent of 20%, causing considerable losses in bulb production. The bolts use up the stored edible material of the bulbs. While the environmental conditions are known to influence % bolting, inherent susceptibility to bolting is a varietal character. Evaluation of Indian onion varieties by different scientists has found bolting as high as 39.6%[44,45,50-52].

4.2.8. Doubling of onions

Another important undesirable character that affects the quality of the bulbs for processing is the presence of doubles. Doubling is primarily a varietal character, although it is considerably affected by environmental conditions, including irrigation. Studies on the evaluation of (a) Indian cultivars have found doubles as high as 55.5 %[50,53,48,51] and (b) exotic cultivars have found doubling in 2.9-71.8 % range[54].

4.2.9. Pungency of onions

While highly pungent onions are popular in India, less pungent ones are preferred in other countries for fresh consumption. However, the variability in pungency in bulbs of different cultivars has not been thoroughly investigated[55]. While Indian white onion cultivars contained up to 12.1 μmoles of pyruvic acid/g in agreement with earlier studies on Indian cultivars, Agrifound Light Red contained 12.2 μmoles pyruvic acid[46,56].

Due to high pungency, Indian cultivars can make good quality dehydrated flakes and granules. The coloured varieties like dark red, red and yellow are also used for dehydration, but the quality of dehydrated produce is inferior to that from white varieties[15]. These results are recently confirmed that existing Indian cultivars are not promising for processing[57]. In contrast, cultivars developed by selection such as JV-16, JV-7, JV-12, ARL-2 and ARS-1 hold promise for dehydration by virtue of their higher TSS, bolting resistance, lower % of doubles, higher pungency, adaptability to short-day condition and good yield[57].

5. CONCLUSIONS

While low (9-13%) total soluble solids (TSS) lines are preferred for table purposes, high TSS (18-26%) are most vital attribute for the processing (dehydration) quality of onions, as high solid containing cultivars give higher product yield, at lower cost of processing. To be globally competitive in the dehydrated onion products, high solid lines are therefore a must. This objective is achievable by the development of cultivars, which have (i) ability to grow during *kharif* (rainy season) and *rabi* (winter season), (ii) resistance to bolting during bulb production, (iii) less % of doubles, (iv) high pungency and (v) good yield among the other characters. With an increasing demand for competitive varieties for the processing industry, it is essential to strengthen our efforts for improving onion cultivars, through hybrid generation, using the existing germplasm and available exotic varieties.

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